NOTES ON
APPLIED GEOLOGY

Notes Accompanying the Lectures on Geology Applied to Mining

A Course Given at Michigan College of Mines

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TABLE OF CONTENTS.

CHAPTER III.

Chemistry of Ore Deposition.

CHAPTER IV.

Iron Ore Deposits.

CHAPTER V.

Copper Deposits.

CHAPTER VI.

Lead and Zinc Deposits.

CHAPTER VII.

Silver-lead Ore Deposits.

CHAPTER VIII.

Gold and Silver Deposits.

CHAPTER IX.

COAL, OIL, AND GAS.

ILLUSTRATIONS.

PREFACE.

The following work represents an attempt to gather together the main facts bearing upon the mode of occurrence of the commoner metals and also a few of the non-metallic minerals. The work is in reality the printed notes accompanying the lectures in Applied Geology and is intended primarily to be used in the Michigan College of Mines. The aim on the part of the author, has been, to state briefly, the main facts bearing upon the Structural Geology and mode of occurrence of the ores in most of the large mining camps of the United States. It should be remembered, however, that an attempt to condense the material of a Monograph or professional into a few pages of text is a most difficult task, and very apt to be incomplete. The aim, throughout, has been to state the facts as briefly as possible and to indicate from what report or reports the notes were taken. Frequently an author's exact words are quoted as in certain instances where, to be more brief, would convey the wrong meaning. It is to be hoped, however, that such a collection of facts, will be of value to mining men after leaving college and any suggestion from them relating to recent developments will be very gladly received.

INTRODUCTION.

Before beginning a study of geology applied to mining it is first necessary to take into consideration the structure of the earth's crust. The crust of the earth is divided into two zones: first, a zone of katamorphism or zone of fracture, and secondly a zone of anamorphism or zone of flowage. This division is based upon the fact that similar forces produce opposite results, owing to changed conditions of temperature and pressure with depth. For example, certain chemical reactions which take place in a certain way in the upper zone under ordinary conditions of temperature and pressure are reversed in the lower zone under conditions of high temperature and enormous pressure. The following, pertaining to the character of the earth's crust and the forces which are active therein, is a very brief statement of some of the essential principles laid down by C. R. Van Hise in Monograph 47, U. S. G. S.

CHAPTER I.

THE EARTH'S CRUST.

Zone of Fracture.—The zone of fracture extends from the surface of the earth to a depth of from 10,000 to 12,000 meters for strong rocks under quiescent geological conditions. The rocks of this belt may contain many openings. The pressure is such that most rocks undergo deformation by fracturing. Temperature and pressure are moderate. Those chemical reactions which take place in this zone are governed by chemical affinity, and not by pressure. Since pressure is not a dominating influence, and since openings exist in the rocks in this zone the dominant reactions are such as liberate heat and increase volume.

Zone of Flowage.—The zone of flowage extends from the lower limit of the zone of fracture as far down as anything is known regarding the crust of the earth. Within this zone the rocks undergo deformation by flowage. In order to ascertain the depth at which flowage will occur it is necessary to know the crushing strength of different kinds of rock. It has been ascertained by actual experiment that the crushing strength of granite is about 25,000 pounds per square inch. Of limestone about 16,000 pounds per square inch. Of sandstone about 6,000 pounds per square inch and of shale considerably less than sandstone. Therefore, if the weight of the column of rock overlying any rock mass is equal to the crushing strength of that particular rock, it will undergo deformation by flowage. In determining the overlying weight the average sp. gr. (2.7) of rocks of the earth's crust is taken into consideration, and since all openings are filled with water, the hydrostatic pressure of which tends to support the rocks, the sp. gr. (1) of water is also considered. From the crushing strength of the different rocks it is evident that the upper limit of the zone of flowage for sandstone is much higher than that for granite. There is, therefore, no well-established line separating the zone of fracture from the zone of flowage, but in reality be-

tween the two there is a zone of combined fracture and flowage. Since temperature and pressure are enormous, pressure and not chemical affinity is the dominant factor in determining chemical reactions; therefore those reactions occur which decrease the volume.. The chemical reactions common to the zone of fracture are oxidation, hydration and carbonation; while those common to the zone of flowage are deoxidation, dehydration and silication. The upper zone or zone of fracture is divided into:

1. The belt of weathering.
2. The belt of cementation.

The Belt of Weathering.—The belt of weathering extends from the surface of the earth to the level of ground water. The thickness of this belt would depend therefore upon the depth of the level of ground water, and that varies according to the following factors:

1. The amount of precipitation.
2. The character of the topography.
3. The character of rocks, size and character of openings, etc.
4. The proximity to streams, lakes or ocean.

The Amount of Precipitation.—All other things being equal, the greater the precipitation, the less the thickness of the belt of weathering and the higher the level of ground water.

The Character of the Topography.—The level of the ground water tends to follow the surface of the ground. For example, if from a lowland a steep hill rises abruptly, the ground water also rises and tends to follow the surface of the ground, but the rise in the ground water level is not nearly so marked as that in the surface of the ground, so that if one were to sink a well from the top of the elevation it would not be necessary to go as deep as the level of the ground water under the lowland to strike water, but it would be necessary to sink much deeper beneath the surface than would be required to strike water anywhere in the valley or lowland.

The Character of Rocks, and Number of Openings, etc.—If the openings are numerous and large, the level of ground water is apt to be a considerable distance beneath the surface for two reasons; first, meteoric waters are able

to make their way readily downward, and secondly, the effect of capillarity is to raise the water in small capillary tubes, but where the openings are mainly large, the force of capillarity would not be of much importance, and therefore there is apt to be considerable change in the level of ground water where the openings in the rock change from capillary to super-capillary size. For example, in fractured limestone regions, with numerous caves, the level of ground water may follow closely the drainage of the district and the belt of weathering will be very thick, especially where the limestone formations are cut by deep canyons, as, for example, in the Grand Canyon regions of Colorado where the level of ground water is 1,000 meters below the surface.

The Proximity of Streams, Lakes or Ocean.—The nearer the approach to streams, lakes or ocean, the nearer the level of ground water is apt to approach the surface. The above general principles are illustrated by the following districts of the United States:

1. Throughout the humid regions of eastern United States the level of ground water varies from 0 to 30 meters below the surface.

2. Throughout the greater part of the drift-covered region the level of ground water is reached at a depth of less than 15 meters.

3. Throughout the disintegrated region of the southern Appalachians the ground water is reached at less than 30 meters.

4. Throughout the high limestone region of Kentucky and Tennessee ground water extends from 60 to 90 meters below the surface.

5. Throughout the greater portion of the western part of the great plateau region east of the Cordilleras, ground water is reached at a depth of from 30 to 75 meters.

6. In arid regions, cut by deep canyons, the level of ground water is found 1,000 or more meters below the surface. The average depth of ground water throughout the United States is from 30 to 50 meters.

Water in the Belt of Weathering.—The only water in the belt of weathering ordinarily is that held by imbibition; that is, by adhesion between the water and the mineral particles. In sub-capillary tubes this attraction extends from wall to wall. In capillary tubes the attraction does

not extend from wall to wall, and a portion of the water may be drawn off if the surrounding liquid is moved. The difference between the water of saturation and the water of imbibition, that is that which may be drawn off, is known as the water of hygrometricity.

In arid regions a large part of the belt of weathering may contain only a fraction of the water of imbibition, while, on the other hand, in many humid regions the belt of weathering contains more than the water of imbibition or a part of the water of hygrometricity. Locally, and for a time, the belt of weathering may be completely saturated. The water which is contained in the belt of weathering is only a small fraction of that included in the belt of cementation.

Chemical Work in the Belt of Weathering.—Chemical work is accomplished by the following agents: (1) Plants, (2) animals, (3) water and gaseous solutions.

PLANTS.—The most important action of non-bacterial plants is abstraction of carbon dioxide from the air, and its reduction and combination with other elements so as to produce various vegetable tissues. The amount of carbon dioxide in the air is only about 3 volumes in 10,000. Therefore, the air in the belt of weathering where plants do not exist probably does not contain a much larger proportion. However, by the action of chlorophyll-bearing plants, and red, brown and blue-green algæ and by one class of bacteria the carbon dioxide of the atmosphere is reduced and the carbon is concentrated in plants mainly as cellulose, which contains 44.4 per cent. carbon. This cellulose when dead is acted upon by bacteria, oxygen and moisture, and furnishes a number of active acids, which are important in connection with superficial alteration of ore deposits.

Plants also contain combined nitrogen, but the great majority of plants are unable to obtain their nitrogen from the air. The main original source of combined nitrogen may be traced to nitrogen bacteria. These make their home in the nodules upon the roots of leguminous plants such as peas, beans, etc. The bacteria abstract, and the leguminous plants store nitrogen compounds in the fruits, stalks and roots. When these plants die these compounds become the source of nitrogen acids and salts which are important geological agents. Plants also ab-

stract certain ingredients from the soil, such as potash, soda, lime, phosphoric acid, etc. Plant roots give acid reactions which corrode the rocks chemically, producing marked disintegration.

ANIMALS.—Animals are not so important for our consideration and will be neglected.

WATER AND GASEOUS SOLUTIONS.—Activity of solutions is dependent upon: (1) Compounds present, (2) temperature, (3) pressure.

Compounds Present.—Water solutions contain considerable amounts of salts formed by the union of the bases and acids which ordinarily occur in the rocks. The compounds in the ground water usually consist of the bases Na, K, Ca, Mg, Fe and Al and the acids carbonic, hydrochloric, nitric, hydrosulphuric, sulphuric, phosphoric and colloidal silicic. The dominant salts are Na, K, Ca and Mg in the form of carbonates, sulphates and chlorides.

Where the rocks are not saturated with H_2O gaseous solutions are also present and active. Of these oxygen and carbonic acid are the most important chemical agents. All of the above compounds, in all of their forms, are actively at work decomposing the rocks.

Temperature.—The belt of weathering is only subject to the changes due to climatic conditions. The average annual temperature near the Arctic Circle in North America and Asia is about $-15°$ C. That of the tropics reaches 27° C. Since solutions are much more active at higher temperature the total of rock decomposition is much greater in the tropics. With temperature below freezing, chemical action practically ceases.

Pressure.—Pressure in the belt of weathering is simply that due to atmospheric conditions and is not of sufficient importance to be taken up here.

The most important reactions in the belt of weathering are: (1) Oxidation, (2) carbonation, (3) hydration, (4) solution, (5) deposition.

OXIDATION.—The source of oxygen is the atmosphere, of which it comprises 23.12 per cent. by weight. Oxygen acts directly as a gas, but to far greater degree through solutions and through water solutions and organisms combined. These organisms are bacteria, molds and fungi. By oxidation, different substances are acted upon differently. By the oxidation of cellulose, organic acids are

produced, and as decomposition continues the organic acids are oxidized and broken up and the ultimate products are carbon dioxide and water. The process of carbonation is due largely to the concentration of carbon dioxide by this process. Nitrogen is oxidized to nitric acid and in uniting with bases forms nitrites and nitrates. The most important of the oxidized, inorganic compounds are iron and carbon. These are the most important from a geological standpoint. From the standpoint of ore deposits, and therefore in reference to the needs of man, the oxidation of the less abundant metals is more important. They will be considered in detail under secondary concentration.

Oxidation of Iron.—Iron occurs as ferrous iron in oxides, carbonates and silicates. Of the oxides magnetite is the most important. Magnetite is oxidized directly to hematite as shown by pseudomorphs of hematite after magnetite in martite-bearing schists of the Lake Superior region. Oxidation and hydration combined produce limonite. Iron may occur as pure iron carbonate or as iron carbonate in combination with varying proportions of Ca and Mg. Oxidation of the iron carbonate changes it to ferric oxide with liberation of carbon dioxide. The changing of the ferrous iron of the silicates to ferric iron is accompanied by hydration and carbonation of the other bases.

The most important sulphides of iron are marcasite, pyrite and pyrrhotite. When the oxidation of the iron and the sulphur occur together and remain together the result is the production of iron sulphate. Sometimes a portion of the sulphur separates as hydrosulphuric, sulphurous or sulphuric acids, which react upon the bases forming sulphates. Deoxidation sometimes takes place in the belt of weathering, where abundant vegetation accumulates near the water level and does not completely decay. Instances of such deposits are sphagnum mosses of marshes which result in deposition of peat. The gray or white clay seams near coal beds show that reduction of the iron has taken place. The iron in ferrous condition readily unites with carbon dioxide, forming iron carbonate so frequently found closely related with coal seams and furnishing the material for chalybeate springs.

CARBONATION.—The carbon dioxide stored up in the outer

part of the crust of the earth is available for the process of carbonation. Carbonation is chiefly accomplished through the substitution of carbonic for silicic acid. It has been shown experimentally that water at ordinary temperature and pressure, containing carbon dioxide, is capable of attacking many minerals. Such silicates as orthoclase, hornblende, olivine, serpentine, mica, etc., were readily acted upon. The process of carbonation formed carbonates of Na, K, Ca, Mg and Fe. The liberated silica partly went into solution and partly separated out as quartz. It was also found experimentally that water containing carbon dioxide at ordinary pressure attacked basalt, phonolite, gneiss, granite, clay, slate and porphyry. Combining the fact that carbon dioxide solutions decompose the silicates with the fact of the abundance of carbon dioxide in the outer crust of the earth one would expect that the process of carbonation would be most rapid in regions of abundant vegetation. This expectation has been confirmed. Thos. Belt observed that in tropical America decomposition of rocks is largely confined to forest regions. It has also been observed that where vegetation is abundant the amount of dissolved silica contained in underground water is much greater than where vegetation is absent.

It has been shown experimentally that the alkaline carbonates are capable of decomposing the silicates at ordinary temperature and pressure so that the formation of alkaline carbonates through the presence of carbon dioxide in water favors further decomposition. Soils containing carbonates are fertile and favorable to abundant vegetation. Vegetation promotes carbonation. Carbonation provides carbonates and therefore promotes vegetation. There is therefore a constant action and reaction.

Hydration.—Hydration is the most extensive reaction in the belt of weathering. All the so-called anhydrous silicate minerals of igneous, sedementary and metamorphic rocks which have been long in the belt of weathering are more or less hydrated. Also the new minerals which develop in this belt are strongly hydrated. Such are kaolin, serpentine, talc, chlorite and zeolite. While hydration is the rule for the belt of weathering, in regions of high temperature and which are not continuously humid, dehydration may take place. Dehydration is most

liable to take place in regions of high temperature where dry and wet seasons alternate. This process is illustrated by iron. Ferric iron in the belt of weathering is usually hydrous and gives a yellow color. In regions of high temperature and low humidity for at least a portion of the year the soil is likely to be red, the iron being in the form of hematite instead of limonite or geothite. Such a region is the desert range of California in which dark red is the dominant color.

SOLUTION.—Along with oxidation, hydration and carbonation, the underground waters are constantly taking substances into solution. The dominating processes of carbonation and hydration transform the compounds into more soluble form. It was stated on page 5 that the activity of solution is dependent upon compounds present, pressure and temperature. These factors will be considered separately.

Compounds Present.—No substance is wholly insoluble in ground solutions even at ordinary temperature and pressure. This is illustrated by the solution of quartz and the more refractory silicates at the surface. Under conditions of deep water circulation, solutions of quartz and refractory silicates may go on with great rapidity. The dissolving of the pebbles of the Calumet and Hecla conglomerate and their replacement by copper is a good example. The influence of one compound on the solubility of another compound is of great importance. The law is that a unit of solution simultaneously saturated with each of several compounds contains a greater total of solid than a unit of solution saturated with fewer of these compounds but less of any individual salt than it would were it saturated with that salt alone.

Pressure.—In general, the volume of the solvent plus that of the dissolved compound is greater than that of the solution. There are some cases, however, where the combined volume of the compound and solvent is less than that of the solution. Ammonium chloride in water is an example. It is clear, therefore, that in the more common case, pressure increases solubility, for solution tends to bring the molecules closer together and acts in conjunction with pressure. Barus found, experimentally, that when soft glass is dissolved in water at temperatures above 210° C., the volume of the solution is 20 to 30 per

cent. less than the two separately. This glass is one which contains alkalis, alkaline earths and lead and is similar in composition to many natural silicates. In the majority of complex underground solutions the total of the salts in solution are, in general, increased by pressure.

Temperature.—For most substances, moderate increase of temperature increases solution. But for many substances there exists a temperature at which there is maximum capacity for solution. For various substances this maximum capacity lies between 60° C. and 140° C. and for many substances it is probably below 200° C. It is highly probable that up to temperatures of 100° C. and therefore under normal conditions to depths of 3,300 meters increase of temperature increases the capacity of ground water to hold minerals in solution. Since solution also increases with pressure it is probable that the combined effect of temperature and pressure increases solution to much greater depth. Barus[1] has shown, experimentally, that at temperatures above 185° C. and less than 200° C. it is possible to impregnate glass with water to such an extent as to make it fusible below 200° C.

Of the above three factors, controlling solution, the one of greatest importance in the belt of weathering is compounds present. If all the important bases contained in the rock-making minerals were equally abundant, the stronger bases would be taken into solution to greater extent than the weaker ones. There would be dissolved more Na and K than Ca and Mg. More Ca and Mg than Fe and more Fe than Al. Again, the greater the proportion of bases present as compared with acids, the more readily the minerals are decomposed and the greater the amount of bases dissolved. Further, if the acids were present in equal quantity there would be dissolved a greater amount of salts of the stronger acids than of the weaker acids. There would be a greater quantity of sulphates, nitrates and chlorides than of carbonates, but since in the solutions carbonic acid is so much more plentiful than any other active acid, carbonates greatly predominate. T. Mellard Reade calculates that throughout the entire globe there is removed annually 96 tons of material per square mile, which he divides as follows:

[1] Barus, C., "Remarks on Colloidal Glass," *Am. Jr. Sci.*, 4th Ser., vol. 6, 1898, p. 270.

Calcium carbonate, 50 tons, calcium sulphate, 20 tons; sodium chloride, 8 tons; silica, 7 tons; alkaline carbonates and sulphates, 6 tons; magnesium carbonate, 4 tons; oxide of iron, 1 ton.

DEPOSITION.—Substances dissolved in the greatest quantity are deposited in the greatest quantity. In limestone regions calcium carbonate is deposited on a large scale in the form of travertine, stalagmites and stalactites. Where evaporation is easy deposition will predominate; where it is not easy, solution will predominate. Upon the whole, however, solution is dominant in the belt of weathering.

Belt of Cementation.—The belt of cementation is that part of the zone of fracture extending from the level of ground water to the zone of flowage. It is so named from the fact that cementation is the most important single process in the belt. Mining activity the world over shows a tightening of the ground below the level of ground water. The rocks are deformed by fracture. The openings are chiefly of capillary and super-capillary size. Rocks brought into this belt are immediately subjected to cementation. Sandstones below the level of ground water show enlargement of the individual grains and deposition between the grains. Cementation continues until sandstone is changed to pure quartzite. Since the rocks are self-supporting in this zone they fracture into great masses by faulting, into blocks by jointing, into layers by movement along bedding planes or other planes of weakness, into slices by fissility and into irregular fragments by brecciation. No sooner are the openings produced than cementation begins filling them with calcite, quartz and other cementing material often dissolved from the belt of weathering. The filling of large openings, such as caves, is well known in the Missouri lead and zinc fields. There the caves, often 60 meters in length by 12 to 15 meters in width, are partly filled with crystallized calcite. The calcite crystal continued to grow until the level of ground water due to pumping passed below them. No stalagmites or stalactites occur in this belt.

Chemical Work.—The chemical work of the belt of cementation is accomplished by water solutions. The range of temperature at which these solutions act is from 0° to 365°, the critical temperature of water. The pressure at

which solutions act varies from one atmosphere to that of a column of water to the bottom of the zone of fracture. Supposing the bottom of this zone to be 10,000 meters, the maximum pressure would be 1,000 Kg. per square centimeter. The chemical work in this belt also is due to oxidation, hydration, carbonation, solution and deposition. Oxidation and carbonation are of much less consequence, but such is not the case with hydration, solution and deposition. Solution and deposition are of fundamental importance.

Oxidation.—Ordinarily water passing from the belt of weathering into the belt of cementation contains oxygen in solution. The following conditions are favorable to deep oxidation in the belt of cementation: (1) A very porous belt of weathering, (2) absence of luxuriant vegetation, (3) descending circulation converging a large amount of underground water, (4) great difference in topography so as to furnish large head, (5) presence of large joints or faults furnishing trunk channels for rapidly descending circulation. It has been shown by numerous observations that the amount of oxygen in the water decreases with depth. Decreasing oxidizing effects are well shown in mining regions where ore deposits are located along joints, faults or other trunk channels. One of the best illustrations of oxidation extending to considerable depth is that furnished by the iron ores of the Lake Superior region. Here the process of oxidation has produced great ore bodies to a depth of 300 meters and exceptionally has reached depths of 500 to 700 meters. An instance of oxidation extending to great depth is the San Juan District of Colorado, where oxidation has gone on to a marked degree to a depth of 600 meters and is noticeable to a depth of 1,000 meters. In contrast with the above are other districts where waters ascend almost to the surface; as for example, the Missouri-Kansas lead and zinc district. There oxidation has scarcely gone below the level of ground water. While oxidation locally becomes important, on an average it is of little importance in the belt of cementation as compared with the belt of weathering.

Carbonation.—Water which passes from the belt of weathering to the belt of cementation contains considerable carbon dioxide as well as oxygen. Since carbon

dioxide is produced abundantly in the belt of weathering where vegetation is abundant through oxidation of carbon, the conditions for abundant carbonic acid in the waters joining the belt of cementation are luxuriant vegetation. Therefore the waters which carry carbon dioxide abundantly are not apt to carry much oxygen. The waters of the belt of cementation have four important sources of carbon dioxide: (1) From the belt of weathering, (2) from the decomposition of carbonates in the belt of cementation through oxidation, (3) from the oxidation of organic material which has been buried in the belt of cementation, (4) from the silication of carbonates in the zone of anamorphism. From the discussion of processes in the belt of weathering the first three sources are evident. Regarding the fourth source a little explanation is necessary. Carbonation was given as one of the fundamental processes of the zone of fracture. The carbonation of the silicates in the belt of weathering has far-reaching effects. The process liberates a large quantity of silica, some of which separates out as quartz, and some being carried away as colloidal silicic acid. In the zone of flowage this process is reversed, the silica liberated from above replacing carbon dioxide of the carbonates, producing silicates and liberating carbon dioxide. To illustrate: Silication of calcite forms wollastonite; silication of ankerite forms sahlite and actinolite; silication of dolomite forms tremolite and wollastonite; silication of rutile and calcite together forms titanite. A portion of the carbon dioxide freed by silication probably escapes to the belt of cementation. A part of it does not escape, which no doubt explains the innumerable cavities partly filled with water and carbon dioxide which are so generally found in the sedimentary rocks metamorphosed in the zone of flowage. It follows from the above that carbon dioxide abundantly supplied to the waters of the belt of cementation will react upon various compounds producing carbonates. It should be remembered, however, that carbonic acid is a much less active agent than oxygen. Carbonation takes place slowly and frequently the carbonic acid does not succeed in uniting with the bases. This explains the abundance of carbon dioxide in many of the famous springs of the world, as those of Shasta and Carlsbad and of the waters rising in many mines.

Hydration.—The belt of cementation might almost equally as well have been called the belt of saturation. Therefore the conditions are ideal for hydration. In this belt the great group of hydrous silicates form most abundantly. It is the home of the hydrous mica, the chlorites, zeolites, epidotes, serpentine, limonite and gibsite. The increase in volume during the process of hydration, providing the compounds remain "in situ," varies in most cases from 20 to 50 per cent.

Solution and Deposition.—Solution and deposition are processes of great importance in the belt of cementation. While at first thought it might be supposed that solution is subordinate a close analysis shows that this process is not less important than depoition. The quantity of water that passes through the belt of weathering and enters the sea of underground water is substantially equal to that which emerges from this sea through springs and through seepage and joins the run off. As regards the relative amounts of the salts entering and issuing from the belt of cementation we must resort to general reasoning. Where the soils are fine and contain many soluble substances and the water percolates slowly it may be saturated for many substances when it reaches the belt of cementation. On the other hand, where the soils are coarse and thin and underlain by porous or fractured rock, the water on reaching the belt of cementation may be far from saturated. After the waters join the belt of cementation they sometimes take a short journey, but often a very long one before issuing at the surface. The artesian waters which issue at Chicago probably entered the ground in central Wisconsin from 150 to 250 years before. In any case the movement of ground water is exceedingly slow. It is evident, therefore, that the circulation of water in the belt of cementation involves a vertical and horizontal component. During the horizontal circulation there is constant tendency for solution, since temperature and pressure are constant. Again, the temperature of the issuing water is usually higher than when entering the belt of cementation. Even if the temperature were the same, solution would be apt to take place, since increase in temperature as the water descends greatly accelerates solution and as the water ascends precipitation takes place only when saturation is reached. From the above it is

expected that ground waters contain more substances in solution when they issue from the belt of cementation than when they enter it, although there is continual interchange of material. From the above, how are we to explain the process of cementation constantly going on in the belt of cementation, the action of which is so rapid that sandstones of Eocene age are completely changed to quartzite? One of the best illustrations of complete cementation is found in the San Juan breccias of Colorado. This formation, 1,500 meters in thickness and originally very porous, has every ancient opening from great fissures to pores between the particles of ash completely filled. Although solution is probably the more important process, cementation is explained by the fact that the chief reactions in the belt of cementation are oxidation, carbonation, and most especially hydration which results in a volume increase of from 15 to 50 per cent. Since ore deposition depends largely upon circulation of ground water, and since the circulation of ground water depends upon character of the openings they will be considered from the following points of view: (1) Form and continuity of openings, (2) size of openings, (3) percentage of openings or pore space.

Form and Continuity of Openings.—For a given cross section, in proportion as an opening approaches a circular form with a minimum of wall area per unit of volume, the flow increases because the friction between the moving water and the film of fixed water upon the walls is less per unit volume. In proportion as the openings are continuous in rocks, the flow increases. Openings in rocks include: (1) Those which are of great length and breadth as compared with their width, such as those of bedding partings, faults, joints and fissility. (2) Openings in which the dimensions of the cross sections are approximately the same, such as those of mechanical deposits including conglomerates, sandstones, soils, tuffs, etc. (3) Irregular openings, such as those of vesicular lavas and the irregular fractures of rocks.

Class 1.—Bedding partings are parallel to the layers, are places of maximum differential movement and consequent complex fracturing and therefore of large circulation parallel to the formations. Faults, joints and fissile openings usually traverse the beds cutting pervious and

impervious beds and are, therefore, of great consequence in the vertical movement of ground water. As to continuity, bedding partings are apt to be most continuous, faults next, joints next and fissile openings are least continuous. Faults may have great continuity, *e. g.*, thrust faults of 15 kilometers along the dip are known and along the strike they may extend for even hundreds of kilometers. They frequently sever and displace impervious strata and connect pervious strata separated by impervious strata, becoming exceedingly important in the circulation of ground water. Joints are less continuous than faults, but much more numerous. They may extend across an entire formation or even across two or more contiguous formations. Their extent along the strike may be many kilometers. Being more numerous they are, in that respect, of more importance than faults in the vertical movement of ground water, but less important in that joints frequently do not pass through relatively plastic impervious strata. Fissile openings are of considerable importance in the flowage of ground water, but not as important as bedding partings, faults and joints.

Class 2.—The openings of mechanical sediments have a strong tendency to a definite form and are continuous. The openings alternately narrow and widen. At the narrowest places the openings are roughly triangular. Slichter has shown that there are various natural systems of packing the particles, but for each system each opening is connected with every other opening, and there is at least one direction in which the tubes are straight, and that this direction determines the direction of flowage of ground water.

Class 3.—Irregular openings may be of any form. In lavas they are frequently spherical or ovoid. In compact rocks they are the irregular interspaces between the mineral particles. Vesicular lavas sometimes have a pore space of 75 per cent. or more. In such an extreme case the openings are more apt to be continuous than where the pore space is small. In general, irregular openings are discontinuous.

Size of Openings.—The size of openings is very important in the circulation of ground water. The size of openings must be carefully discriminated from the per cent. of opening or pore space. Two rocks may have the

same pore space while in one the openings may be very large and in the other very small. Upon the basis of size, openings in rocks may be divided into (1) Super-capillary, (2) capillary and (3) sub-capillary openings.

According to Daniell[2] *Super-capillary Openings* are circular tubes exceeding .508 mm. in diameter, or sheet openings whose widths exceed one half of this, or .254 mm. The area of contact and therefore the friction between the moving water and the fixed film of water attached to the walls of the tubes is inversely as the size of the openings. Furthermore, internal friction in super-capillary tubes is dependent upon the viscocity of the solution, regularity of the openings, upon their length and size and upon velocity of flowage. Super-capillary openings include the greater number of bedding partings, fault openings, joint openings, some of the openings of fissility and those of coarser mechanical sediments, such as coarse sandstones and conglomerates.

Capillary Openings.—Capillary openings include those which, if circular tubes, are smaller than .508 mm. in diameter, and if sheet openings, are narrower than .254 mm., and larger than sub-capillary openings. Capillary openings include most openings of sands and sandstones, many of the openings of conglomerates, of porous lavas and many openings produced by fracture. The maximum size of grains of sand of uniform size, the smallest openings of which are capillary, is 3 mm. in diameter. As a matter of fact, capillary openings in mechanical sediments range from very fine sands to very coarse sands. Many openings of fissility are capillary, but the majority of bedding partings, fault openings and joint openings are, in part, super-capillary. In capillary openings the resistance to flow increases very rapidly as the tube diminishes in size. The volume and velocity of flow in an elliptical cylinder varies but slightly from those of a circular tube. A slight change in the shape of the cross section of a capillary tube will change but slightly the flow through it. A concise statement of some of the laws governing capillary flow as given by Daniell is as follows:

Laws of Capillary Flow.—The flow in capillary tubes

[2] Daniell, Alfred, "A Text-book of the Principles of Physics," 3d edition, The Macmillan Co., New York, 1895, pp. 315–317.

is proportional to the fourth power of the radius. Velocity is proportional to pressure. Resistance varies directly as the velocity—in wide tubes approximately as the square of the velocity. This apparent discrepancy is due to the formation of eddies in the large tubes. Poiseuille's Law is that the flowage is inversely as the viscosity. The viscosity of water decreases rapidly with increase of temperature. This is a very important factor in effecting the flow through capillary tubes in the underground circulation of water.

Sub-capillary Openings.—To this class belong the openings of the great majority of clays, shales and slates and the minute openings between the grains of igneous rocks and rocks metamorphosed to schists and gneisses. These are openings in which the attraction of the molecules of rock, or other solid substance, extends from wall to wall. There is no free water in the sense that molecules are free to move among themselves. The flow of water in sub-capillary tubes as compared with capillary openings is immeasurably slow, but water under high temperature and pressure has small viscosity, hence increase of temperature increases the flowage in sub-capillary openings. Ground water at all temperatures below the critical temperature under ordinary conditions is held by the pressure in the form of a liquid. But at temperatures higher than 365° C., or the critical temperature of water, whatever the pressure, the water is in the form of water gas. In this form it may be supposed to have a much greater penetrating power than in the form of liquid. That water gas does not obey the law of flow of liquids in sub-capiliary tubes is shown by the experiment of Daubree[3] in which the vapor of water, at a temperature of 160° C. and under a pressure of 6 atmospheres, passed through a layer of apparently solid rock 2 cm. in thickness and exerted a pressure on the other side of 1.9 atmospheres. This experiment shows, beyond all question, that water gas under high temperature and pressure does not adhere to the walls strongly and has such a small viscosity that it slowly but surely passes through sub-capillary openings. It also shows that heated waters, down deep in the zone of anamorphism where temperature and pressure is high,

[3] Daubrée, A., "Geologie Experimentale," Paris, 1879, vol. 1, pp. 236–238.

must slowly work their way through the small sub-capillary openings characteristic of that zone.

Pore Space or Percentage of Openings in Rocks.—The pore space in rocks varies from a fraction of 1 per cent. to 50 per cent. or more. Some compact limestones absorb as small as .20 per cent. by weight of water which corresponds to a pore space of about .55 per cent. Ordinary compact limestone, used for building material, absorbs from 1 per cent. to 5 per cent. by weight of water which corresponds to a pore space of 2.5 to 12.5 per cent. Very porous limestones contain as high as 25 per cent. pore space.

Sandstones ordinarily are very porous and hold from 2 or 3 to 15 per cent. of water by weight which corresponds to a pore space of from 5 to 28 per cent. Capacity to hold about 10 per cent. by weight of water and therefore a pore space of about 20 per cent. is common for sandstone. In clay loams and clays, pore spaces as high as 50 per cent. were obtained by King. He suggests that this high pore space may possibly be partly explained by the angularity of the grains so characteristic of the fine mechanical sediments.

Some igneous rocks are dense and originally had a small amount of pore space. When a succession of thinly bedded, basic lavas, are piled up one on the other, the pore space averages as much as in ordinary sandstones, but from this maximum the average runs down as the flows become thicker, and the average pore space of vesicular lavas is not more than one third to one half as great as in the mechanical sediments.

Forces Which Drive Water Through the Openings are: (1) Gravity, (2) heat, (3) mechanical action, (4) molecular attraction and (5) vegetation.

Gravity.—The dominating force is gravity. Gravity ever tends to pull water down and this force always at work continuously carries circulating water to lower levels, but the downward movement of a great mass of water results in the upward movement of a lesser mass. Gravity is effective in the movement in proportion to the head. Where there is a difference in the density of the two columns due to difference in amount of material held in solution, gravity promotes circulation independently of head.

Heat.—Heat results in expansion and contraction of water and such changes in volume necessarily involve movement. Taking the volume of water at 4° C. as 1, its volume at 50° C. is 1.0120, at 75° C. is 1.0258 and at 100° C. is 1.0432. Therefore, increase in temperature of underground water may increase its volume and lessen its density as much as 4 per cent. without exceeding its boiling point at atmospheric pressure. The downward moving water is ordinarily dispersed in many small openings and moves slowly and at any given place has approximately the temperature of the rocks. The upward movement is usually through the larger openings and relatively rapid. Therefore, at any given place, its temperature is probably higher than is normal for the rocks at that depth. The result is a difference in temperature between the descending and ascending columns, the ascending column being the warmer.

Mechanical Action.—Earth movements may close or partly close the openings of rocks and squeeze out the water as in the production of schists and gneisses from sedimentary rocks.

Molecular Attraction.—This attractive force works between the particles of water themselves (cohesion) and between the particles of water and rock (adhesion). As a result, water may rise against gravity in capillary openings and raise the water level.

Vegetation.—The roots of plants absorb ground water and transfer it to the surface. This causes a relative deficiency of water which causes a movement of water toward the roots.

CHAPTER II.

VIEWS REGARDING ORE DEPOSITION.

We are now in condition to take up ore deposits. Knowing that openings of various kinds may exist in the zone of fracture and that cementation is one of the dominant processes in the belt of cementation, it is natural to suppose that these openings in time become filled, in part at least, with substances carried in solution and finally deposited. The openings may be entirely filled with some metallic compound of commercial value and of sufficient quantity to become valuable ore deposits. On the other hand the opening may be filled, in part, by valuable metallic compounds, but largely by some substance of little value such as calcite, quartz, barite, etc., commonly known as gangue. The deposits, if they occur as fillings, will take on the form of the openings, and, as a matter of fact, in nature we have deposits filling fault and joint openings, the openings along bedding planes, the irregular openings of vesicular lavas, the circular openings of amygdaloids, disseminated deposits filling the small openings of mechanical sediments and many others. The next question which naturally arises is: What is the source of the metallic compounds filling these openings? Regarding the source of these compounds our best authorities on ore deposition are not in entire agreement. We shall now take up the main views on the subject.

Lateral Secretion Hypothesis. — By lateral secretion is understood the derivation of the contents of a vein from the wall rock. Three interpretations may be made according to this hypothesis. (1) That the vein has been filled by the waters near the surface which seep from the walls of the opening. (2) The second interpretation supposes the walls to be, during the time of filling, at considerable depth below the surface, so that the percolating waters are brought within the region of elevated temperature and pressure. (3) The third interpretation supposes the vein to extend to great depth through rock of the same kind and to derive its contents from a great

amount of rock of the same kind as the walls, portions of the rock to be in regions of high temperature while the place of precipitation is nearer the surface.

In favor of the lateral secretion hypothesis the following arguments have been advanced. (1) According to Sandberger actual experience with the conduits, either natural or artificial, of mineral springs shows that a deposit seldom if ever gathers in a moving current. It is only when solutions come to rest on the surface and are exposed to oxidation and evaporation that deposition takes place. He argues that deposits in veins have therefore formed in standing waters. (2) The second argument is that when veins are opened up which traverse two different kinds of rock, in the vein which traverses one rock, one kind of ore and gangue mineral is frequently found, while in the portion of the vein crossing the other kind of rock, a different kind of ore and gangue mineral is found. In such a case the wall rock clearly had some influence. As an illustration of the above conditions, may be cited that at Klausen, in the Austrian Tyrol. Lead, silver and zinc occurred in the veins where they cut diorite and slates, but copper, where mica schist and felsite formed the walls. Also, in America, at the Silver Islet Mine, on Lake Superior, the vein runs through unaltered flags and shales and then crosses and faults a large diorite dike. Where the diorite forms the wall the vein carries native silver and sulphides of lead, nickel, zinc, etc., but where the flags form the walls the vein contains only barren calcite.

From instances like the above, it is inferred that the ores were derived each from its own walls and by just such a leaching action as stated above.

Deposition by Ascending Solutions.—According to this view it is assumed that the material that fills a lode has been brought up in solution from great depths and not from the rocks in the immediate vicinity of the lode. In his classic memoir, on "The Genesis of Ore Deposits," Professor Franz Posepney offers some very strong arguments in favor of this view, some of which are given as follows: Ascending waters encountered in mines. In the Gottes Geschick Mine, in the Erzgebirge, at a depth of 110 meters, an acid spring containing carbon dioxide and hydrogen sulphide emerges from a nickel and cobalt-

iferous silver ore vein. A thermal spring of 23° C. was struck at a depth of 533 meters in the Einigkeit Shaft at Joachimthal and, in the same mine, at two other points similar mineral springs, rising with strong pressure, were exposed. They prevented further increase in depth of that part of the mine and were plugged, as far as possible. Also, at the Comstock Lode, ascending thermal waters were unexpectedly encountered, the abundance and high temperature of which presented great obstacles to mining. The upper workings were not especially hot, but at a later period, on cutting through certain clay partings of the rock, the hot water repeatedly broke into the workings with great force and in the North Ophir Mine scarcely gave the workmen time to escape. The water had a temperature of 40° C. and filled the openings immediately to a height of 100 feet. Becker found that the increase in temperature with depth was much greater in the vicinity of the lode than away from it, showing that the vehicle of heat was the water and that it was through the lode itself that communication with the heated depths took place. At Sulphur Bank, California, sulphur, cinnabar and opaline silica occur in fissures of decomposed basalt. These fissures gave forth hot mineral waters charged with hydrogen sulphide which oxidized to sulphuric acid, the acid which decomposed the rock. In these fissures amorphous silica was seen in gelatinous condition enclosing masses of cinnabar. The silica being in this condition was clearly deposited by heated ascending waters, and since it enclosed particles of cinnabar that sulphide undoubtedly had a like origin. Equally weighty evidence of the work of ascending solutions is furnished by Steamboat Springs, Nevada. In a valley surrounded by eruptive rocks, thermal springs may be seen at several points emerging from north and south fissures. The action of these springs has covered the ground with a sinter deposit about 15 meters thick. Through this sinter are many fissures, some of which emit vapors and some are closed. G. F. Becker carefully analyzed the filling of several fissures and found them to contain, besides hydrated ferric oxide, considerable quantities of Sb, As, Pb, Cu and Hg sulphides and Au and Ag as well as traces of Zn, Mn, Co and Ni. Further evidence of the work of a succession of ascending solutions is shown in the fact that in most

channels extending to the surface, and still uninjured, a regular filling with symmetrically arranged mineral crusts may be observed. For example, in Transylvania the filling of a fissure 10 inches wide consists of variegated crusts of aragonite as thin as paper, the fibers of which are perpendicular to the walls of the channel. The latest crusts are dark and give a bituminous odor, the older ones are milky white and leave a residuum of gelatinous silica.

Deposition by Igneous Processes.—The recent advocates for the direct igneous origin for certain ore deposits include Vogt, Beck, Kemp, Spurr and others. It is a well-known fact that many ore deposits are more or less closely associated with masses of igneous rock with which they are genetically connected. To just what extent the metallic contents of the deposits have come, directly from the cooling magma, and to what extent from the surrounding rocks, through the influence of superheated waters, is open to discussion. Igneous contacts are frequently ore-bearing for the following reasons: (*a*) Differentiation of the cooling magma tends to segregate the highly basic and the metal-bearing portion at the border of the cooling mass. (*b*) Pneumatolytic processes are more active about the borders of igneous masses. (*c*) The force of the intrusion may have shattered the adjacent rocks, forming cracks and fissures that become the channels for circulating waters. (*d*) The shrinkage of the intrusive magma, due to progressive cooling after solidification, and the shrinking of the metamorphosed zone itself, would result in the formation of fissures. (*e*) The porosity induced in certain sedimentary rocks by contact metamorphism (which may be compared to the burning of clay into brick) has furnished channels for circulating waters so that ore deposition has resulted. The process (*a*) above is commonly known as the magmatic segregation. Where elements exist in the magma, in sufficient quantity, they sometimes segregate to such an extent as to form workable deposits. Authorities on ore deposition are not in full agreement as to the importance of this process. Professor Vogt has been one of the most vigorous advocates of magmatic segregation and gives the following list of deposits which he believes to be of direct igneous origin. (1) The occurrences of titanic iron ores in basic and in-

termediate eruptives, perhaps also of iron ores in acid eruptives; (2) those of chromite in peridotites and their secondary serpentines and those of corundum in the peridotites of North Carolina; (3) a number of deposits of sulphide ores particularly the nickeliferous pyrrhotites occurring in gabbro at Sudbury, Can., Lancaster Gap, Pa., many places in Norway and Sweden and Varillo in Piedmont; (4) the auriferous pyrites of Russland, B. C.; (5) the high-grade copper ores occurring in serpentinized peridotites in Tuscany and Liguria, northern Italy; (6) the occurrences of metallic nickel iron in eruptive rocks, and (7) those of the platinum metals in highly basic eruptive rocks. It should be remembered that aluminum and iron are the two most abundant metals in nature and are most likely, during crystallization, to segregate as oxides to such an extent as to produce ores. The average amount of metallic iron in original igneous rocks is 4.64 per cent. and in the basic rocks in which the magnetic iron ores occur is as high as 8.66 per cent., as in the Duluth gabbro of Minnesota. To produce an ore body by magmatic segregation in such a magma the iron would only need to be increased about seven times. On the other hand in the original igneous rocks the amount of Cu, Ni, Co, Au, Ag, etc., are usually so small as not to be detected by assay. In order to produce ores of these metals, segregation would have to take place in many cases more than a thousand fold.

Deposition by Gaseous Solutions.— Ores are frequently deposited by heated vapors of different kinds, emanating from the magma or by heated circulating waters or by the two combined. Gases and vapors exist dissolved in the molten magma within the earth's crust. They play an important part in volcanic activity, some of them showing themselves in the earliest and most energetic stages of a volcano's history, while others continue to issue from the ground centuries after all other subterranean action has ceased. By far the most abundant of them all is water gas, which escapes as steam and has been estimated to form .999 of the whole cloud that hangs over an active volcano. The hottest and most active vapor vents may contain all the gases and vapors of a volcano, but as the heat diminishes the series of gaseous emanations is reduced. For example, in the Vesuvian

eruption of 1855–56 the lava, as it cooled and hardened, gave out successive vapors of hydrochloric acid, chlorides and sulphurous acid; then steam; and finally carbon dioxide and combustible gases. More recent observations indicate that the nature of the vapors evolved depends upon the temperature or degree of activity of the volcanic orifice, chlorine and fluorine emanations indicating the most energetic phase of eruptivity, sulphurous acid, a diminishing condition, and carbonic acid with hydrocarbons, the dying out of the activity. Even from volcanoes like the "Solfatara" of Naples, which have been dormant for centuries, steam sometimes still rises without intermission and in considerable volume. The above gases combined with some others escaping through funnels or "fumeroles" as they have been called or through fissures, often deposit substances such as sulphur, ferric chloride, cupric oxide, salts of boron, etc. The second group of deposits resulting from the action of gases alone are usually referred to as solfataric, fumorolic, or pneumatolytic deposits. The deposition of cinnabar by solfataric or fumorolic vapors has been advocated very strongly by some writers owing to the ease with which it is sublimed. Daubrée has maintained that tin ores are formed by the sublimation of stannic chloride and stannic fluoride and their reaction upon water. However, it is highly probable that ores formed by gaseous solutions alone form a very subordinate class.

Deposition by Gas-aqueous Solutions.—More important than all other deposits associated with igneous rocks, are those deposits which result from the action of gaseous and aqueous solutions combined. The intrusion of great masses of igneous rocks into the earth's crust not only gives off gases but also heats the water circulating through the surrounding rocks to a very high temperature, perhaps often to the critical temperature. This gives the water a much greater solvent power enabling it to dissolve out fine particles of metallic substances disseminated throughout the surrounding rocks. Furthermore, the gases given off by the magma and often carrying metallic substances mingle with the surrounding water in all proportions. Finally, these waters by cooling, by mingling with other solutions, or by some other process deposit their load. Often, as in the case of Sul-

phur Bank, or Steamboat Springs, these heated solutions rise to considerable distance along some fissure, and perhaps to the surface before depositing their load. The actual intrusion of the igneous material itself, as shown on p. —, under (*c*), (*d*) and (*e*), furnishes the conditions for a much freer circulation and for mingling of solutions of different kinds. The question naturally arises with reference to each contact deposit as to how much of the metal came directly from the igneous material and how much came from the surrounding rocks through the increased activity of circulating solutions.

In his article entitled "Ore Deposits Near Igneous Contacts" Mr. Walter H. Weed, of the United States Geological Survey, says: "In many mining districts there occur great masses of granitic rocks surrounded by sedimentary strata which, near the contact, exhibit marked alteration, the intensity of which diminishes as the distance from the igneous rocks increases until the alteration fades out and the rocks are of normal character. Such areas are known as contact metamorphic zones which often form a halo around igneous centers. For example, about the stocks of granitic rocks of the Crazy Mountains, Montana, or the batholitic masses of the Black Hills, Dakota. In other cases great areas of granitic rock, such for example, as the great mass of granite called the Butte batholith, of Montana, which is sixty miles long and forty miles broad, are bordered by a zone of rock altered by contact metamorphism which may be a mile or more wide, as for instance, near Helena, Montana. Such contact zones are often the seat of mineral deposits of great economic value as is illustrated by the Drumlummon and other mines at Marysville, Montana; several mines at Phillipsburg, Montana, the Whitlatch Union and other mines, once productive, at Helena; the copper mines at Clifton and Morenci, Arizona; those of Cananea, Sonora and many other localities in Mexico. These contact metamorphic deposits, of whatever type, are distinguished by a gangue consisting essentially of garnet, calcite, epidote, actinolite with or without accessory wollastonite, vesuvianite, fluorite, etc., and other minerals, characteristic of contact metamorphic zones. The gangue is normally a rock formed by the alteration of impure limestone. Other rocks, characteristic of contact action, such as hornfels,

marble, quartzite, adinole, etc., are often present, but the ore deposit is practically confined to the rocks, resulting from the alterations of impure limestone." The ore deposits of the Boundary District of British Columbia according to S. F. Emmons are of contact metamorphic origin. The ores carry from 2 to 5 per cent. copper and a few pennyweights of gold per ton. The ore bodies occur in belts of metamorphosed limestone two miles or more wide, that are adjacent to a mass of light gray, coarsely crystalline granitic diorite. The Cananea Copper Deposits are situated in Cananea Mountains, fifty miles southwest of Bisbee, Arizona. The range is from six to twelve miles wide and twenty-five miles long. It rises 4,500 feet above the surrounding plain. The mountain range consists of the dissected and denuded remains of an old volcano, probably of Tertiary Age. At Puertecitos Pass there is a central core of granite surrounded by massive andesite and baked and altered sedimentary rocks. The main crest of the mountain, southward, consists of marble, hornstone, quartzite, and garnet-epidote rocks, resulting from intense alteration of impure limestone by the heat of igneous intrusion. These rocks are cut by large intrusions of quartz porphyry, and small diabase dikes. The ores consisting, of chalcopyrite, copper glance, pyrite, zinc blende and a little galena occur in beds of altered limestone tilted at steep angles and also in fractures along and across the quartz porphyry and quartzite.

Secondary Concentration.—By secondary concentration is meant the superficial alteration of ore deposits, and usually the removal of certain constituents of the deposits through the activity of descending waters and the redeposition of those constituents at lower levels usually throughout a zone immediately below the level of ground water. This zone is usually called the zone of secondary enrichment and is characterized by the presence of sulphide ores. It is evident that the depth of this zone will depend, to considerable extent, upon the depth of the level of ground water and also upon the presence or absence of conditions favoring deep oxidation below ground water level. The process of secondary enrichment is one of exceeding importance in that many of the richest concentrations of ore owe their existence to this process.

CHAPTER III.

CHEMISTRY OF ORE DEPOSITION.

In order to obtain a clearer conception of the process of ore deposition it is necessary to consider some of the most abundant elements from the standpoint of solution and deposition. In other words, to consider how they are carried in solution and some of the influences which result in their precipitation. The following, pertaining to the chemistry of ore deposition is a brief synopsis of some of the principles and examples laid down by C. R. Van Hise in Monograph 47, U. S. G. S.

GOLD.

Gold has long been known to be soluble in ferric chloride and in cupric chloride. Doelter[1] has shown that it is somewhat soluble in a 10 per cent. solution of sodic carbonate and also an 8 per cent. solution of sodic carbonate containing an excess of carbonic acid and containing sodic silicate. Becker[2] has shown it to be soluble also in sodic sulphide and in sodic sulphydrate. Stokes has found gold to be soluble in a ferric sulphate solution where chlorides are present. Lehner has shown, by experiment, that gold is soluble in sulphuric acid, phosphoric acid and various other acids, if a compound be present which liberates oxygen, *e. g.*, manganese dioxide. This process may go on to a considerable extent in nature, since all of the compounds occur rather abundantly in nature and gold ores are frequently associated with manganese minerals. Van Hise concludes that since the -ic salts are produced abundantly in the belt of weathering, and since gold is soluble in ferric and cupric chloride, in acids where oxygen is liberated and possibly in ferric sulphate, these processes are supremely important in the segregation of

[1] Doelter, C., "Einige versuche über die Löslichkeit der Mineralien," *Tschermak's Mineral. Mittheil.*, vol. 11, 1890, p. 329.

[2] Becker, G. F., "Geology of the Quicksilver Deposits of the Pacific Slope," Mon. U. S. Geol. Survey, vol. 13, 1888, p. 433.

gold. Iron sulphide is frequently abundant in auriferous quartz veins. The reaction of oxygen upon it produces ferric sulphate and by its decomposition sulphuric acid is formed. Where chlorine is present ferric chloride is produced. Copper sulphide would be acted upon in a similar manner to that of iron with the production of similar compounds.

Precipitation.—In whatever form gold is carried it is known to be precipitated in the first concentration as metallic gold and as a telluride. Whether it is also precipitated as a sulphide is uncertain. Hall and Lehner[3] have recently shown that tellurium completely precipitates gold from its solution according to the following reaction:

$$4AuCl_3 + 3Te = 4Au + 3TeCl_4.$$

They have also shown that selenium precipitates gold from its solutions in a similar manner according to the following reaction:

$$4AuCl_3 + 3Se = 4Au + 3SeCl_4.$$

The rapid precipitation of gold from its solution by contact with iron, copper and silver is well known. Gold is also precipitated from its solutions by many -ous salts and oxides, *e. g.,* ferrous sulphate readily reduces gold to the metallic condition. Stokes has shown that ferrous salts in silicates will precipitate copper from its solutions and evidently gold may be precipitated in like manner. Probably ferrous oxide, in magnetite, is also adequate to precipitate gold from its solutions. Stokes has determined, experimentally, that the following reactions occur as indicated below:

$$AuCl_3 + 3FeCl_2 = Au + 3FeCl_3$$

also

$$AuCl_3 + 3CuCl = Au + 3CuCl_2.$$

He states that with rising temperature the equilibrium moves from left to right, with falling temperature from right to left. It follows, therefore, that where there

[3] Hall, R. D., and Lehner, Victor, "Action of Tellurium and Selenium on Gold and Silver Salts," *Jour. Am. Chem. Soc.*, vol. 24, 1902, p. 919.

is lessening temperature, ferrous chloride and cuprous chloride reduce gold solutions, throwing down the metallic gold. Normally the conditions for falling temperature are those for ascending solutions and hence by the above reactions gold is more apt to be deposited where waters are ascending. Van Hise says it may be stated with a fair degree of certainty that any of the ferrous and cuprous compounds which occur in nature are adequate precipitating agents for gold solutions. From the description of various gold deposits it seems to him very probable that in many instances the ferrous salts have been important reducing agents, and the same may be true of cuprous compounds. Since deep in the belt of cementation where organic matter and sulphides are abundant, -ic salts are changed to -ous salts, and therefore the trunk channels which carry gold in solution are likely to receive contributions from other solutions which carry -ous salts in large amounts. The law of mass action now demands the reduction of the gold to its metallic condition. For instance, if the gold were a chloride and ferrous sulphate were present, the following action would take place:

$$2AuCl_3 + 6FeSO_4 = 2Au + 2Fe_2(SO_4)_3 + 2FeCl_3.$$

Organic material is capable of precipitating gold from its solutions. The precipitation of gold has been ascribed, in part at least, in many places to the influence of organic matter. Rickard calls attention to the frequent association of metallic gold with sedimentary rocks bearing organic matter in California, New Zealand, Australia and Tasmania. The most remarkable case is the concentration of gold in veins where they cross strata of carbonaceous shale called indicators. Says Don: "Away from the indicator the greater part of the vein quartz is absolutely barren; but at the intersection with the indicator large masses of gold (often more than 100 ounces in one piece) have been obtained, and the greater part of the gold extracted from this belt has come from those parts of the quartz veins near some one of the indicators. Rickard describes experiments in which the black carbonaceous shale of Rico was placed in silver solutions and in solutions containing Cripple Creek gold ore. Both metal-

lic silver and gold were abundantly precipitated upon the shale in a short time. Sulphides of the baser metals also precipitate gold from its solutions. Gold occurs on a great scale associated with pyrite, and very frequently with sulphides of other metals, especially copper. Liversidge has shown, experimentally, that pyrite, galena, arsenopyrite and nearly all other sulphide minerals will precipitate gold completely from solutions of auric chloride.

Recently Lehner and Hall have shown that the natural tellurides of gold, silver and mercury are capable of rapidly and completely precipitating metallic gold from its solutions. This they have accomplished with calavarite, kremierite, sylvanite, hessite, kalgoorite, nagyagite and coloradoite. This experimental work of Lehner and Hall probably largely explains the intimate association of free gold with the tellurides at various places. Lehner and Hall have shown that silver selenide also reduces gold to metallic form almost as fast as selenium does.

SILVER.

Silver most extensively occurs as a sulphide. The sulphide is often oxidized to a sulphate which is readily soluble in water and is undoubtedly transported to great extent in that form. It is also certain that silver is also transported to some extent as a chloride. It is also soluble in ferric sulphate, the reaction being:

$$2Ag + Fe_2(SO_4)_3 = Ag_2SO_4 + 2FeSO_4.$$

Silver is doubtless soluble, to some extent, in all the strong acids which occur underground and also in their salts. Silver occurs to some extent in metallic form.

Precipitation.—The precipitation of silver follows similar lines to that of gold, but not being so readily reducible as gold is not thrown down in metallic form by so many compounds. It is precipitated by metallic iron, by metallic copper, by cuprous compounds, readily by ferrous sulphate and probably slowly by all other ferrous compounds. The precipitation of silver by ferrous sulphate is commonly written:

$$Ag_2SO_4 + 2FeSO_4 = 2Ag + Fe_2(SO_4)_3.$$

4

If the ferrous sulphate is abundant, and the temperature moderate, it is believed that the more probable reaction for the precipitation of silver from its solutions is represented by the following equation:

$$Ag_2SO_4 + 3FeSO_4 + 4H_2O = 2Ag + Fe_3O_4 + 4H_2SO_4.$$

Silver may be precipitated by ferrous compounds in solid form, as in magnetite and the silicates. This is evidently the case since such compounds are capable of reducing copper to metallic form and this element is more difficult to reduce than silver. That such reduction has taken place by ferrous iron of silicates, has been held by Vogt for the native silver of Kongsberg, Norway.

COPPER.

Copper in underground solutions is probably carried largely as copper sulphate. It is also carried as a chloride. It may also be carried as copper carbonate in carbonate solutions carrying excess of carbonic acid. As a sulphide it is soluble in the alkaline sulphides, especially acid sodium sulphide (NaHS) and is soluble in considerable quantity in alkali sulpharsenates and sulphantimonates.

Precipitation.—It is precipitated as a metallic compound by metallic iron and by ferrous compounds. The latter process is by far the most important. Copper occurs most extensively in metallic form as precipitate of a first concentration in the Lake Superior region. The close association between native copper and iron-bearing minerals carrying ferrous iron was pointed out by Pumpelly many years ago. That copper is reduced by ferrous compounds was confirmed by experimental work when Stokes, by heating an acidified solution of cupric sulphate and ferrous sulphate in a closed tube, produced metallic copper at the cold end of the tube and pure hematite at the hot end. The reactions involved are as follows, in both directions:

$$2CuSO_4 + 2FeSO_4 = Cu_2SO_4 + Fe_2(SO_4)_3.$$

The Cu_2SO_4 is decomposed on cooling to Cu and $CuSO_4$ while $Fe_2(SO_4)_3$ decomposes on heating, thus:

$$Fe_2(SO_4)_3 + 3H_2O = Fe_2O_3 + 3H_2SO_4.$$

Stokes was also able to reduce cupric sulphate to metallic copper by heating with hornblende in a closed tube to a temperature of 200° C. The reduction he attributes to ferrous iron silicate of the hornblende.

Where the ferrous salts are in excess it is probable that the natural reaction would produce magnetite, a compound not oxidized to the extent of ferric salts. The reaction may be expressed as follows:

$$CuSO_4 + 3FeSO_4 + 4H_2O = Cu + Fe_3O_4 + 4H_2SO_4.$$

By this reaction three molecules of the ferrous salts are required to produce one molecule of metallic copper, whereas if ferric salts be produced only two molecules of ferrous compounds are needed. That the above reaction does occur in nature is indicated by the close association of native copper and magnetite in the Nonesuch sandstone of the Lake Superior Region.

Sulphides.—The metals occurring as sulphides comprise iron, copper, lead, zinc, nickel, arsenic, antimony, mercury and silver. Of these, iron is the most abundant. As to their origin it is well known that sulphide of iron occurs as an original constituent of igneous rocks. Probably the same is true of other sulphides. The large amount of sulphur issuing from the interior of the earth in connection with volcanism leads to the conclusion that sulphides must exist in the igneous rocks. It is, therefore, highly probable that sulphur as sulphide was present in sufficient quantity in the original rocks to fully account for all the sulphur compounds of the ore deposits.

Solution.—It is well known that the sulphides of copper, mercury, iron, nickel, lead, zinc, arsenic and antimony are soluble in alkaline sulphides. Becker has shown that the sulphides of iron, copper, zinc, arsenic and antimony are all soluble in alkaline carbonates containing, but not saturated with, hydrosulphuric acid. This is partly equivalent to saying that they are soluble in sodium sulphide; for if hydrogen sulphide is put into a sodium carbonate solution the following reaction immediately takes place:

$$Na_2CO_3 + H_2S = Na_2S + H_2O + CO_2.$$

Since alkaline carbonates are so abundant in ground

waters, and since hydrogen sulphide is common in such solutions, without doubt sodium sulphide is very important in the genesis of ores. This supposition is confirmed by observation at Steamboat Springs, Nev., and Sulphur Bank, Cal., where mercuric sulphide and iron sulphide are transported in solutions containing Na_2S, H_2S, Na_2CO_3 and CO_2.

Doelter has shown that sulphides are soluble in pure water to some extent. He has dissolved measurable quantities of pyrite, galena, stibnite, sphalerite, chalcopyrite, arsenopyrite and bournonite. While the sulphides are somewhat soluble by various compounds it is not supposed that the materials are carried in the form of sulphide only. The sulphides are largely oxidized to sulphites and sulphates in the belt of weathering. The sulphates of iron, copper, zinc, nickel, mercury and silver are all readily soluble. Even the sulphate of lead is dissolved to the extent of 1 part in 31,500 parts of water at 15° C., which is probably sufficient for purposes of underground transportation.

Precipitation.—The above shows some of the different ways in which the more common economically important elements may be transported as sulphides. The question now arises as to the conditions which will result in their precipitation. Sulphides may be precipitated in the following ways:

1. By Dilution of the Compounds, or that Combined with Decreasing Temperature and Pressure.—In general, water solutions increase their solvent power as they descend, owing to increased temperature and pressure. Later, as they rise through trunk channels of circulation under conditions of decreasing temperature and pressure, the different compounds are precipitated in reverse order to that in which they were taken into solution.

2. By Mingling of Solutions.—For instance, if an acid, such as boric or sulphuric acid, be added to the solutions of the sulphides carried in alkaline carbonates and alkaline sulphides, simple neutralization will result in precipitation of many of the sulphides. There the alkaline sulphide, the solvent, is destroyed. *E. g.,* in the following reaction:

$$Na_2S + H_2SO_4 = Na_2SO_4 + H_2S.$$

In this case not only is the solvent destroyed, but a precipitating agent (H_2S) is produced. Where the sulphides are transported in solutions of Na_2S and Na_2CO_3, the addition of hydrogen sulphide in excess will result in the precipitation of many of the metals. The mingling of acid and alkaline solutions is very apt to result in precipitation where strongly alkaline solutions bearing sulphides, in rising from the deep sources, meet descending strongly acid solutions resulting from the oxidation of sulphides to sulphates near the surface.

3. **By Reduction.**—Wherever below the level of ground water the sulphates and sulphites come in contact with organic material the sulphates and sulphites may be reduced to sulphides. Precipitation may result indirectly, *e. g.*, if silver be transported as a chloride with sodium sulphate in the solutions, if oxygen is extracted from the sodium sulphate, it would be transformed to sodium sulphide, which would immediately precipitate the silver as silver sulphide. Again, if copper is travelling mainly as a carbonate, if sodium sulphate is present, and the reducing agent be carbon, the result is represented by the following reaction:

$$CuCO_3 + Na_2SO_4 + 2C = CuS + Na_2CO_3 + 2CO_2.$$

The precipitation of sulphates as sulphides is frequently caused by the presence of H_2S. This compound is produced on a large scale as follows:

(*a*) By the action of dilute strong acids upon the sulphides.

(*b*) By the partial oxidation of the sulphides, *e. g.*, the following reaction may take place:

$$3FeS_2 + 4H_2O + 4O = Fe_3O_4 + 4H_2S + 2SO_2.$$

The frequent association of magnetite with iron sulphide, where the conditions have been favorable for partial oxidation, suggests that the reaction may have taken place on a large scale. The H_2S produced as above indicated may join the circulating water, bearing oxidized salts, and precipitate copper, zinc, lead, silver and other metals as sulphides. Precipitation may occur and, from many natural occurrences, undoubtedly does occur through the pres-

ence of ferrous compounds. This is strongly suggested by the intimate relation which exists between native copper and many of the ferrous iron compounds in the Lake Superior Region.

4. Precipitation of Oxidized Compounds by Sulphides of the Other Metals.—Schurmann gives the following series of metals, the order being increasing strength of affinity for sulphur: Manganese, thallium, arsenic, iron, cobalt, nickel, zinc, lead, tin, antimony, cadmium, bismuth, copper, silver, mercury, palladium. He shows that sulphide of the first member of the series, manganese, reacts upon the oxidized salts of the following metals and precipitates them as sulphides, the precipitating agent at the same time going into solution as an oxidized salt. In this connection it is well to note that iron sulphide, one of the most abundant sulphides in nature will precipitate most of the other metals, which undoubtedly explains the intimate relationship between secondary sulphides of copper and the pyrite or marcasite in the belt of secondary concentration. It is seen that manganese will precipitate any of the other metals in the list. In this connection it is well to note the widespread occurrence of rhodochrosite and rhodonite in connection with ore deposits. They have been especially noted at the Butte and Little Belt Mountains District of Montana; in the San Juan, Cripple Creek and Aspen Districts of Colorado. The rich gold streaks in the Camp Bird Mine, Colorado, are associated with impure rhodonite. Also in the Golden Fleece vein rhodochrosite, with quartz, forms the gangue of the rich free gold ore. If manganese should be present in the veins as a sulphide, and oxidized solutions of any of the other metals come in, the sulphides of the other metals would be formed, and manganese would pass to the oxidized condition and be precipitated as a carbonate or silicate, because carbonic and silicic acid are very abundant and form, with manganese, insoluble compounds.

CHAPTER IV.

IRON ORE DEPOSITS.

Throughout the following discussions of districts the aim has been to condense only that subject matter of the monographs and professional papers, which treats of the geology, structural features and character and mode of occurrence of the ores. The particular report from which the notes are taken, in all cases, heads the list of references. The following general statement is made in order that the student will see clearly the relative values from the standpoint of annual production of some of the more important metallic and non-metallic elements. The value of the production in 1906 was as follows:

Pig Iron	$505,700,000
Copper	177,595,888
Gold	94,373,800
Lead	39,917,442
Silver	38,256,400
Zinc	24,362,668

Next to zinc in value of the production stands aluminum which amounted, in 1906, to $4,262,286. The value of the remaining metals is insignificant as compared even with aluminum. While it will not be possible to consider all the different ways in which the six most important metals occur in nature, yet certain districts have been selected for the purpose of pointing out the relation which exists between certain structural features, such as folding, faulting, jointing, bedding, brecciation, igneous intrusion, etc., and the existence of ore-bodies. The metals will be taken up almost to the exclusion of the non-metallic minerals, not because of their greater value from an economic standpoint, for the total value of anthracite and bituminous coal in 1906 exceeded that of pig iron by $7,379,809. The value of petroleum was approximately equal to that of gold, and the value of the natural gas product exceeded that of silver by more than eight and one half millions of dollars. Again, the value of clay products, cements and lime, exceeded the total product of gold, silver, lead and zinc by

about thirty-two millions of dollars. The total non-metallic production of the United States, in 1906, exceeded the metallic production by more than one hundred and thirty millions of dollars. The more abundant metals will be discussed, therefore, not because of their superior value from an economic standpoint, but because in their origin and mode of occurrence they present problems by far more difficult to comprehend than do some of the more important non-metallic products.

Mesabi District.—The following notes are taken chiefly from Monograph XLIII, U. S. G. S., by C. K. Leith. This range lies in that part of Minnesota, northwest of Lake Superior. It trends nearly east and west with a length of 100 miles and a width of from 2 to 10 miles. It is by far the largest producer of iron ore in the Lake Superior district. Production in long tons from different districts in 1907 was as follows:

Mesabi	27,245,441 long tons.
Menominee	4,779,592 long tons.
Marquette	4,167,810 long tons.
Penokee-Gogebic	3,609,519 long tons.
Vermillion	1,724,217 long tons.

The geological formations of the Mesabi Series lie along the south slope of a ridge known as the Giant's or Mesabi Range.

The succession of formation is as follows:

Cretaceous. (Unconformity.)	
Keweenawan (Unconformity.)	Great basal gabbro and granite intrusive in all the lower formations.
Upper Huronian (Mesabi series). (Unconformity.)	Virginia slate (upper slate formation) dense fine grained, gray to black, sometimes graphitic. Biwabik iron formation. From 500 to 1,000 ft. Pokegama quartzite and quartz slate. From 0 to 450 ft. in thickness.
Lower Huronian (Unconformity.)	Granite intrusive in lower formations. Slate-graywacke, conglomerate formation, in nearly vertical attitude. Equivalent to Ogishke and Knife formations of Vermillion district.
Archean	Greenstones, hornblende schists and porphyries.

The Giant's Range, though extending nearly east and west, has, near the center, a relatively sharp bend, known locally as "The Horn," which carries the iron-bearing

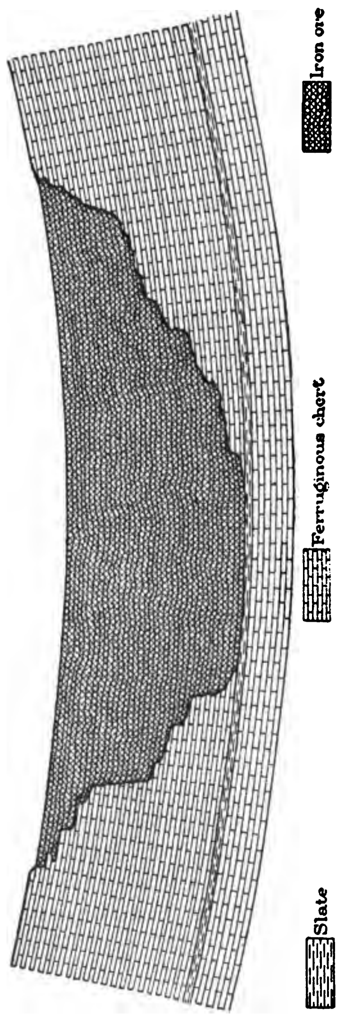

FIG. 1. Ideal cross section of a Mesabi ore deposit showing relation of ferruginous chert and impervious slate layers. (From U. S. Geological Survey, Monograph XLIII, Fig. 9, p. 228.)

rocks six miles to the south. The structure of the horn is that of an anticline with a synclinal trough south of Mountain Iron and west of Virginia. The Archean greenstones and schists are only exposed over a limited area

in the vicinity of the "Horn." Lower Huronian granite forms a continuous belt along the higher parts of the Giant's Range throughout almost its entire extent. Lower Huronian grakwacke and slate is exposed in the anticlinal arch of the "Horn" and in a small area north of Mesabi Station. The Upper Huronian series constitute a great southward dipping monocline, the dips being usually form 5° to 15°. The series is very gently folded in a direction transverse to the range.

Biwabik Iron Formation.—The Biwabik iron formation is underlain by the Pokegama quartzite and overlain by the Virginia slate, and forms a continuous belt from Grand Rapids on the west to Birch Lake on the east. Its breadth varies from less than a quarter of a mile to two miles or more. It presents four widely differing varieties as follows: (1) A lean ferruginous chert, the chert and iron occurring in alternate bands, or irregularly mixed; (2) iron ore bodies; (3) ferrous silicate and carbonate rocks; (4) more or less ferruginous slates. Variety 2 is, of course, the most important from an economic standpoint. Varieties 3 and 4 are usually found in the southern part of the iron formation close to the overlying Virginia slate. Within the Biwabik iron formation are slate layers. These slate layers and their altered phases, commonly called paint rock, underlie many of the larger deposits, as shown in Fig. 1. The cross folding above mentioned produced a series of synclines. The major anticlines and synclines are composed of minor anticlines and synclines. The synclines of the second order of magnitude usually mark the position of ore bodies. Surface waters entering the iron formation flowed along the south dip, converging in the synclines and were ponded under the edge of the Virginia slate. The original iron formation material consisted, to some extent, of iron carbonate, but chiefly of iron silicate, in the form of greenalite granules. Analysis showed these granules to be essentially $FeSiO_3nH_2O$. Surface waters bearing carbon dioxide attacked this hydrous silicate. The reaction was probably as follows:

$$FeSiO_3H_2O + H_2CO_3 + aq. = FeCO_3 + H_4SiO_4 + aq.$$

The $FeCO_3$ was either oxidized and hydrated in place as follows:

$$4FeCO_3 + 3H_2O + 2O = 2Fe_2O_3,\ 3H_2O + 4CO_2,$$

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

or the $FeCO_3$ was taken into solution and precipitated by coming in contact with solutions bearing an abundance of oxygen some time later. The ores were in this way concentrated. The removal of H_4SiO_4 in solution accounts for the slumping of the beds so frequently seen at the contact of the wall rock and the ore bodies.

References for the Mesabi District.

1. Monograph XLIII, U. S. G. S., by C. K. Leith.
2. Bull. No. X, Minn. Geological Survey, by J. E. Spurr.
3. *Eng. and Mg. Jour.*, Vol. 73, p. 277, 1902, by C. K. Leith.
4. *Science*, New Ser., Vol. 15, p. 351, 1902, by C. K. Leith. (Stratigraphy and origin of ores.)
5. *Eng. and Mg. Jour.*, Vol. 79, pp. 698–700, 1905, by D. E. Woodbridge. (Discusses the geology of the Lake Superior iron region.)
6. *Lake Sup. Mg. Inst. Proc.* for 1902, Vol. 8, pp. 75–81 [1903], by C. K. Leith. (Chiefly on origin of the Mesabi and Gogebic ores.)
7. U. S. G. S., 21st Ann. Rept., Pt. 3, pp. 305–434, by C. R. Van Hise and C. K. Leith. (Brief discussion of the Lake Superior district, taking up each range separately.)

Penokee-Gogebic District.—The following notes are taken chiefly from Monograph XIX, U. S. G. S., by R. D. Irving and C. R. Van Hise. The Penokee-Gogebic District is a narrow belt south of Lake Superior running about N. 70° E. The eastern and most profitable third of the district lies in Michigan. The western and less profitable two thirds lies in Wisconsin. The more important mining towns of the district are Hurley, Ironwood and Bessemer. The succession of formations is as follows:

Cambrian	Lake Superior sandstone.
(Unconformity.)	
Keweenawan. (Unconformity.) Upper Huronian series. (Unconformity.)	Tyler slate. Ironwood formation (iron-bearing formation). Palms formation (quartz slate formation).
Lower Huronian ...... (Unconformity.)	Bad limestone (cherty limestone formation). Quartzite and' slate, probably Mesnard.
Archean	Granite and granitoid gneiss. Schists and gneiss.

According to A. E. Seaman the Bad Limestones of this district is, in places, underlain conformably by quartzite and slate which, in all probability, corresponds to the Lower Huronian Mesnard formation of the Marquette district. The greatest thickness of the Bad Limestone observed is 300 feet. It occurs in only a few small isolated patches lying in places unconformably above the basement complex and in places conformably above the Mesnard formation. The Upper Huronian consists of a quartz slate member at the base (Palms formation) with a maximum thickness of 800 feet, a middle iron-bearing formation (Ironwood formation) with an average thickness of 850 feet, and an upper slate formation (Tyler Slate). The iron-bearing series has a northward dip of from 30 to 80 degrees with an average of 60 to 70 degrees. The iron formation, like the Mesabi, is underlain by a quartz slate member and overlain by a slate member. The series forms the south side of the synclinal trough of which the Mesabi series forms the north side. Unconformable above the Upper Huronian lies the Keweenawan. In the central part of the range the iron-bearing formation was separated from the Keweenaw flows by a great thickness of Tyler slate while in the eastern and western ends of the district the Tyler slate was removed by erosion.

Where there is direct contact between the Keweenaw flows and the iron-bearing formation, the metamorphic influence is well shown in the peculiar alteration which the iron-bearing formation has undergone. Also during Keweenaw times great masses of igneous rocks were intruded into the eastern and western parts of the Upper Huronian Series. Consequent upon these intrusions and the great Keweenaw flow, the alternations were of a deep-seated kind. The original cherty iron carbonate was almost completely decomposed, some of the protoxide of iron being partly oxidized to magnetite. Another part of it, with the calcium and magnesium, united with the silica present, forming actinolite. The result was to transform the original cherty iron carbonate to a refractory actinolite, magnetite schist, which surface waters were unable to transform to iron ore. The productive central portion of the iron-bearing formation remained during Keweenaw time as a little altered cherty iron carbonate. When later the district was folded and deeply denuded so as to ex-

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

pose the iron-bearing formation to surface waters, the iron carbonate was readily altered to ferruginous slate, ferruginous chert and locally to ore bodies. When the Huronian rocks were in horizontal position they were in-

FIG. 2.

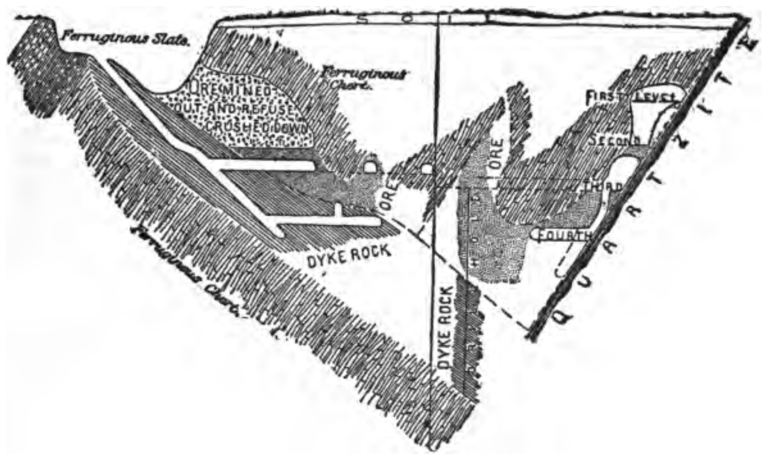

FIG. 2. Cross section of a north and south deposit, Colby mine. (From U. S. Geological Survey, Monograph XIX, Plate XXXI, Fig. 3.)

truded by dikes probably of Keweenaw age. These dikes traverse the sedimentary series nearly at right angles. They also cut the series diagonal to the strike so that when the iron-bearing formation was tilted to the north at angles varying from 50 to 70 degrees, the dikes formed with the foot wall quartzite pitching troughs. This is well shown in the accompanying figure 2.

REFERENCES FOR THE PENOKEE-GOGEBIC DISTRICT.

1. Monograph XIX, U. S. G. S., by R. D. Irving and C. R. Van Hise.
2. U. S. G. S., 21st Ann. Rept., Pt. 3, p. 337, by C. R. Van Hise and C. K. Leith.
3. U. S. G. S., Bull. 86, pp. 150–154, 187–189, by C. R. Van Hise.
4. Iron ores of the Gogebic district. U. S. G. S., 18th Ann. Rept., V, pp. 28, 31; U. S. G. S., 19th Ann. Rept., V, pp. 46, 50; U. S. G. S., 20th Ann. Rept., VI, pp. 33.

The Marquette District.—The following notes are taken chiefly from Monograph XXVIII, U. S. G. S., by C. R.

Van Hise, W. S. Bayley and H. L. Smyth. This district is a comparatively small east-west belt, lying wholly in the state of Michigan and derives its name from the city of Marquette. The succession of formations in descending order is as follows:

Cambrian	Lake Superior sandstone.	
(Unconformity.)		
Upper Huronian	Michigamme formation. Slate and graywacke.	
	Bijiki iron formation..	Iron ores usually limonitic with graphitic slate and grunerite magnetite schist.
(Unconformity.)	Goodrich quartzite and conglomerate.	
Middle Huronian	Negaunee iron formation. (The chief iron-bearing formation.)	
	Siamo slate, containing interstratified amygdaloid.	
(Unconformity.)	Ajibik quartzite.	
Lower Huronian	Wewe slate.	
	Kona dolomite.	
	Mesnard quartzite.	
Archean	Granite, syenite, peridotite.	
	Kitchi schist and Mona schist, the latter banded and in a few places containing narrow bands of iron formation.	
	Palmer gneiss.	

In a broad way the Marquette District is, in structure, a great westward pitching synclinorium. At the west end of the district the Republic trough projects to the southeast. The district is cross-folded in a composite way so that the distribution of the formations is exceedingly irregular. Iron-bearing formations of the Marquette District occur at all four of the horizons at which ores are known in the Lake Superior Region, from the base upward as follows: The Archean ore-bearing formation, the Negaunee formation of the Middle Huronian and two iron-bearing horizons in the Upper Huronian, one at the base of the Goodrich quartzite and the other the Bijiki formation. The iron formation of the Archean is unimportant

from an economic standpoint. The Eureka mine near Marquette produced some iron ore, but has not for many years. The chief iron-bearing formation of the Marquette district is the Negaunee. This covers an extensive area in the neighborhood of Ishpeming and Negaunee. It has a maximum thickness of from 1,000 to 1,500 feet. The iron-bearing formation comprises cherty iron carbonate, ferruginous slates, ferruginous cherts, jaspilites, grünerite magnetite schists, detrital ferruginous rocks and ore bodies. Van Hise says, in 21st Ann. Rept., Pt. 3, of the U. S. G. S.: "The original rock of the Negaunee iron formation was cherty iron-bearing carbonate . . . approaching in places very closely to a siderite. The metamorphism of the formation is less simple than in the Mesabi and Penokee districts in that there have been two periods of alteration. In Inter-Marquette time the erosion cut deep enough to expose the Negaunee formation. The upper part of this formation, which was then in the belt of weathering, was largely transformed into ferruginous slates and ferruginous cherts. In early Upper-Marquette time, detrital material largely derived from the Negaunee formation accumulated; thus making a horizon at the base of the Upper-Marquette series largely composed of iron oxide and quartz. Thereafter the original rock, the weathered products *in situ* and the detrital material were buried under the Upper-Marquette sediments and igneous rocks of that and Keweenaw time were intruded.

"While the rocks were deeply buried they were folded closely. Under these circumstances the original iron carbonate and the secondary material from it yielded very different products. Where original iron carbonate remained, and especially where it was intruded by abundant igneous rocks, it was partly transformed into a grünerite magnetite schist. The iron oxide of the ferruginous slates and ferruginous cherts was dehydrated and these rocks were therefore changed to jaspilites. At the same time the detrital ores at the base of the Upper Marquette were transformed to hematite and jasper-bearing quartzites and conglomerates. Much later, but before Cambrian time the region was again elevated above the sea and folded and denudation cut through the Upper Marquette series and again exposed the Negaunee formation and the adjacent rocks to the agents of weathering. A new set of trans-

formations was then begun. Residual unaltered cherty iron carbonate was still abundant. Where this reached the surface it was transformed into ferruginous slates and cherts. The jaspilites and detrital ores also received a new contribution of iron oxide. It was at this period of alteration that the ore deposits were developed." If the above explanation is entirely true, and if the different kinds of iron formation material were effected as he says by igneous rocks intruded during Upper Marquette and Keweenaw time it seems strange that the great area south of Ishpeming, where igneous rocks are most abundant, is almost entirely without grünerite magnetite schist. Furthermore, if the jaspilites were produced by the action of folding and igneous intrusion on the ferruginous cherts during Upper Marquette and Keweenaw time it is difficult to explain the abundance of jaspilite pebbles in the conglomerate at the base of the Goodrich quartzite. They can hardly be accounted for by dynamic metamorphism of ferruginous chert since the conglomerate was laid down, because the conglomerate also contains pebbles of unaltered ferruginous chert in close association with the jaspilite.

Workable iron ores have been found at many places from east of Negaunee to Michigamme and Spurr, on the northwest, and to Republic on the southwest. The ore deposits of the Negaunee formation may be divided into three classes: (1) Ore deposits at the bottom of the iron-bearing formation; (2) ore deposits within the iron-bearing formation, these ores often reach the surface but are not in the uppermost horizon of the formation; (3) ore deposits at the top of the Negaunee formation and at the base of the Goodrich quartzite.

1. This class includes those deposits which have as their foot-wall the Siamo slate. They are found along the outer borders of the Negaunee formation and usually occur where the Siamo slate is folded so as to form a trough. Examples of this class are the deposits occurring at the Teal Lake Range and east of Negaunee. They include the Cleveland hematite, Cambria, Buffalo, Blue, and other mines.

2. The deposits of class 2 usually rest upon a pitching trough composed entirely of a single mass of greenstone or on a pitching trough, one side of which is a mass

of greenstone and the other side of which is a dike joining the greenstone mass. The masses of greenstone partly enclose several westward opening bays which are occupied by the iron formation. Of such is the Ishpeming basin, the northern Lake Angeline basin, the southern Lake Angeline basin and the Salisbury basin. Mines whose deposits belong to this class are Cleveland Lake, Lake Angeline, Lake Superior Hematite, Salisbury and many others.

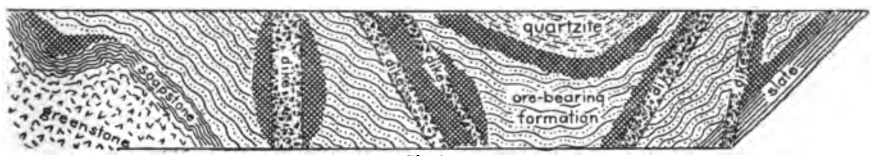

FIG. 3. Generalized section in the Marquette district showing relations of all classes of ore deposits to associated formations. (From U. S. Geological Survey, 21st Ann. Report, Part 3, Plate LIV, Fig. 4.)
On the right is soft ore resting in a V-shaped trough between the siame slate and a dike of soapstone. In the lower central part of the figure the more common relations of soft ore to vertical and inclined dikes cutting the jasper are shown. The ore may rest upon an inclined dike, between two inclined dikes, and upon the upper of the two, or be on both sides of a nearly vertical dike. In the upper cental part of the figure are seen the relations of the hard ore to the Negaunee formation and the Goodrich quartzite. At the left is soft ore resting in a trough of soapstone which grades downward into greenstone.

3. The deposits of class 3 consist chiefly of hard ore, mainly specular hematite, but in some cases considerable magnetite is also present. The ores are always associated with jaspilites or grünerite magnetite schist. The deposits may be bottomed by greenstone or layers of slate within the Goodrich quartzite. As examples of mines of this class are Lake Superior Specular, Volunteer, Michigamme, Riverside, Champion, Republic, Barnum, Kloman and Goodrich. The accompanying Fig. 3 is a generalized section showing relations of all classes of ore deposits to associated formations.

References for the Marquette District.

1. Monograph XXVIII, U. S. G. S., by C. R. Van Hise, W. S. Bayley and H. L. Smyth.
2. 21st Ann. Rept., Pt. 3, by C. R. Van Hise.

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

3. *Mg. World*, Vol. 21, pp. 197–198.
4. Iron ores of the Marquette district discussed in 18th Ann. Rept. U. S. G. S., V, pp. 29–30; 19th Ann. Rept. U. S. G. S., VI, pp. 47, 50; 20th Ann. Rept., U. S. G. S., VI, p. 35.
5. A. I. M. E., Vol. I, p. 193, 1872.

The Menominee District.—The following notes are taken chiefly from Menominee Special Folio, No. 62, U. S. G. S., by C. R. Van Hise and W. S. Bayley. The Menominee District composes a tongue of sedimentary rocks lying between a granite area to the north and a greenstone schist area to the south. It is the southernmost of five distinct tongues which extend eastward from the great central area of Huronian rocks in Wisconsin and Michigan. The geological succession in the Menominee District in descending order is as follows:

Lower Silurian	Chazy. Calciferous.	Hermansville limestone.
Cambrian (Unconformity.)	Potsdam	Lake Superior sandstone.
Upper Huronian or Upper Menominee (Unconformity.)	Hanbury slate, comprising black and gray clay, slates, gray calcareous slates, graphitic slates, graywackes, thin beds of quartzite, beds of ferruginous dolomite and rare bodies of ferruginous slate and iron oxide.	
Middle Huronian or Middle Menominee (Unconformity.)	Negaunee iron formation. Subdivided into the Curry ore-bearing member, Brier slate and Traders ore-bearing member.	
Lower Huronian or Lower Menominee (Unconformity.)	Randville dolomite. Sturgeon quartzite.	
Archean	Granite and gneisses cut by granite and diabase dikes. Quinnesec schists cut by acid and basic dikes and veins.	

Since the ore deposits in this district bear a close relation to the Randville dolomite and occur in the Negaunee iron formation, the following discussion will be almost entirely in reference to those formations alone.

The Randville dolomite occupies three separate belts

whose positions and shapes are determined by the folding to which the formation has been subjected. These belts run nearly northwest and southeast, and are known as the northern, middle and southern belts. Structurally, the northern belt is a southward-dipping monocline. The central and southern belts are anticlines. The southern anticlinal belt reveals the existence of a number of minor folds having almost vertical limbs. In the western part of the district the folds are overturned to the south, the axial planes dipping north at high angles. In the central and eastern part of the district, east of Quinnesec, the minor and major folds have their axial planes steeply inclined to the south. While the minor folds are fairly easily recognized, it is only on the south side of the southern anticlinal belt that they become prominent. Here the minor synclines open out, forming basins in which the ore-bodies lie. The small folds, as a rule, pitch west in the western portion of the range and east in the eastern part. The major anticlines disappear to the east and to the west by plunging beneath the Upper Menominee sediments. The iron formation comprises three members: (1) the Traders ore-bearing member usually lying unconformably above the Randville dolomite; (2) Brier slate lying conformably above the Traders formation, and (3) Curry ore-bearing member lying conformably above the Brier slate. The large ore deposits, as a rule, rest in pitching troughs due to the folding of the Randville dolomite. These relatively impervious troughs may be bottomed either by Randville dolomite, which has been altered to talc schist, by a slate constituting the lower part of the Traders member, or by the Brier slate. Some small deposits occur at the contact between the different members.

Regarding individual deposits, it has been observed that near Iron Mountain are two important folds, superimposed upon which are folds of the third order. The western fold produces the trough in which the Chapin, Millie and Walpole mines are located. The eastern fold produces the trough in which the Pewabic mine is located. The Aragon mine is another good example of ore concentrated in a pitching trough. Fig. 4 shows the structural relations at both the Aragon and Norway mines. Just east of the Aragon mine an amphitheater of dolomite almost entirely surrounds the lowland occupied by the iron formation. A short distance west of this embayment

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

the Aragon ore-body was discovered. With depth the ore-body gradually widened and, at the fifth level, assumed definite relations to the fold in the dolomite.

References for the Menominee District.

1. Menominee Special Folio of U. S. G. S., No. 62, by C. R. Van Hise and W. S. Bayley.
2. 21st Ann. Rept., Pt. 3, U. S. G. S., by C. R. Van Hise.
3. Iron ore analyses. 18th Ann. Rept., U. S. G. S., V, p. 31; 19th Ann. Rept., U. S. G. S., VI, pp. 48, 50; 20th Ann. Rept., U. S. G. S., VI, p. 35.

Crystal Falls District.—The following notes are taken chiefly from Monograph XXXVI, by J. M. Clements, H. L. Smyth, W. S. Bayley and C. R. Van Hise. The Crystal Falls District includes the broad area of Huronian rocks between latitude 45° 45′ and 46° 30′ and longitude 88° and 89°. The greater part of the district is in Michigan and the remainder in Wisconsin. The chief towns of the district are Florence, Commonwealth, Mansfield, Crystal Falls, Amasa and Iron River. The geological succession in descending order is as follows:

Cambrian	Lake Superior sandstone.
(Unconformity.)	
Upper Huronian	Michigamme formation—western continuation of Michigamme formation in Marquette district, comprising graywackes, ferruginous graywackes, micaceous, carbonaceous, and ferruginous clay slates, thinly laminated cherty, siderite slate, ferruginous chert and iron ore.
Unconformity.	
Middle Huronian	Negaunee or Groveland iron formation, consisting of quartz and anhydrous iron oxides, such as magnetite, martite, and specular hematite and a much rarer iron amphibole similar to the grünerite of the Marquette Range. Hemlock formation, consisting almost exclusively of typical volcanic rocks. Mansfield slate, consisting of graywacke, clay slates, phyllites, siderite slates, ferruginous chert and iron ores.
Unconformity.	
Lower Huronian	Kona or Randville dolomite. Mesnard or Sturgin quartzite.
(Unconformity.)	
Archean	Granite.

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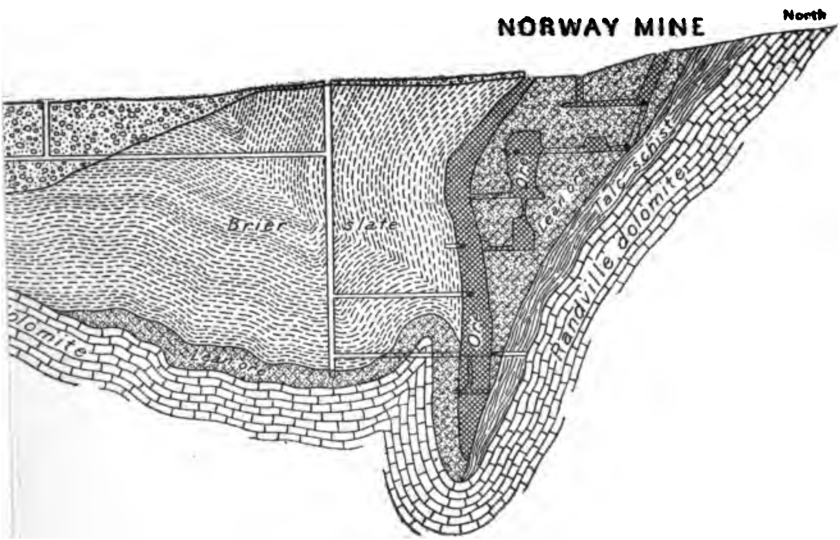

'olio No. 62, p. 8, Fig. 5.)

The ore-bodies in the Crystal Falls District occur at three horizons from the base of the series, upwards, as follows: (1) Within the Mansfield slate; (2) within the Negaunee or Groveland iron formation, and (3) within the Michigamme formation.

1. Within the Mansfield Slate.—Although a large amount of exploring has been done in the Mansfield slate, only one large body of ore has thus far been discovered in which is the Mansfield mine. The ore-body varies from 16 to 32 feet in thickness and is in almost vertical position. It has a well-defined foot and hanging wall consisting of black and red slate, respectively. The ore-body is separated from a mass of greenstone by only a few feet of slate.

2. Within Groveland Formation. — A comparatively small amount of ore—mainly hard and siliceous hematite—has been mined from this formation at the Groveland, Northwestern and Metropolitan mines at the Felch Mountain Range.

3. Within the Michigamme Formation.—Although an iron formation has been found at this horizon, near Amasa, and at two localities north of there, the large deposits occur in the neighborhood of Crystal Falls. The Crystal Falls area is in a synclinorium forking as the result of a subordinate central anticline so as to produce a U-shaped opening to the south of west. It is in this area that the important mines of the Crystal Falls district occur. The ore is chiefly soft, red hematite, though frequently hydrated and graded as brown hematite. The ore is associated with white or reddish chert, in places jaspery. The ore is frequently surrounded by chert beds which are bottomed by black carbonaceous slate. The ore-bodies commonly lie in westward pitching synclinal troughs.

REFERENCES FOR CRYSTAL FALLS DISTRICT.

1. Monograph XXXVI, U. S. G. S., by J. M. Clements, H. L. Smyth, W. S. Bayley and C. R. Van Hise.
2. 21st Ann. Rept., U. S. G. S., Pt. 3, by C. R. Van Hise.
3. *Mg. Mag.*, Vol. 10, pp. 175–183.

Vermillion Iron District.—The following notes are taken chiefly from Monograph XLV, U. S. G. S., by J. M. Clements. The Vermillion District comprises a narrow belt of Archean rocks, in places overlain by those of the Huronian Series, extending in an east-northeast direction

from Vermillion Lake, Minn., to Gunflint Lake on the International Boundary, a distance of about 92 miles. The width of the belt seldom exceeds ten miles, and is often much narrower. The succession is as follows:

Keweenawan (Unconformity.)	Duluth gabbro and Logan sills, intrusive into older formations.		
Upper Huronian		Rove Slate	Black slate with some graywacke and Logan sills.
		Gunflint Formation	Cherts, ferruginous carbonates, grunerite schists, jasper and iron ores.
Unconformity.			
Middle Huronian (Wanting.)			
Lower Huronian		Knife Slate	Aphanitic slate with minor beds of grit and conglomerate.
		Agawa Iron Formation	Slaty carbonate, chert, jasper, iron ore, slate.
		Ogishke Conglomerate	Character of pebbles depends upon the rocks from which they were derived, granite boulders, greenstone boulders, or jasper boulders.
Unconformity.			
Archean	Keewatin	Soudan Iron Formation	Various colored cherts, jasper, and iron ore, often resting on a slaty or conglomerate base.
		Ely Greenstone	Mostly basic igneous rocks, with ophitic, poikilitic or porphyritic textures, and with spherulitic, ellipsoidal or amygdaloidal structure; also tuffs and intrusive dikes.
	Eruptive Contact.		
	Laurentian	Granites, granite porphyry and quartz porphyry predominating.	

The Vermillion District is one of extraordinarily complex folding. Superimposed upon the longitudinal folds are cross folds with very steep pitches, showing that the

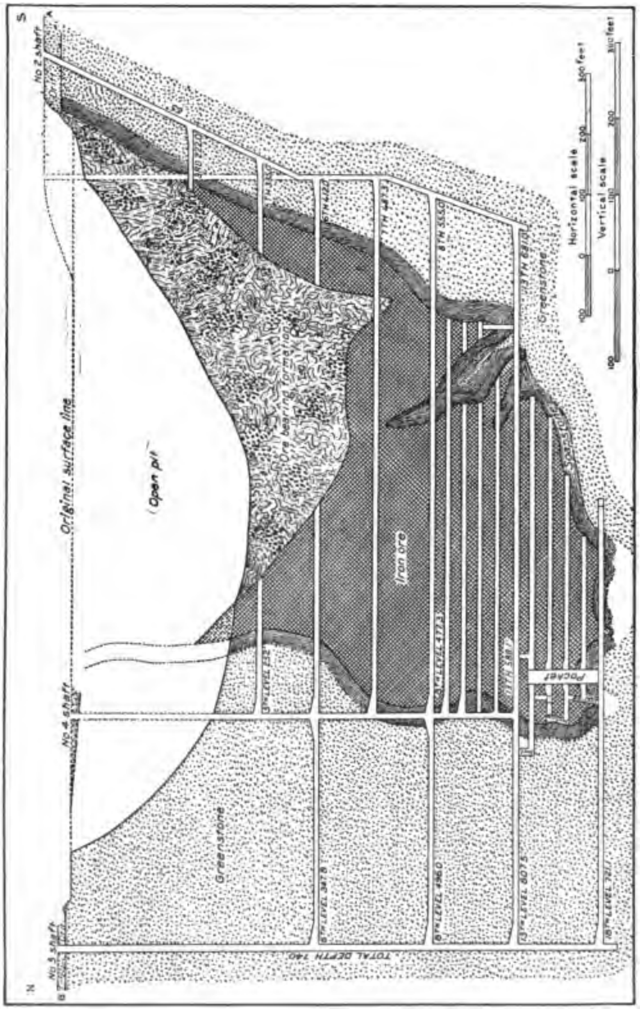

FIG. 5. Vertical section through the Chandler mine. (From U. S. Geological Survey, Monograph XLV, p. 219, Fig. 11.)

transverse folding was also severe. As the result of the folding there is the greatest irregularity in the distribution of the formations. The structure of the district is

further complicated by intrusives of various ages. In the Vermillion District there are iron formations in the Archean, Lower Huronian and Upper Huronian. This district differs from the districts which we have studied, however, in that the iron formation of the Archean is the great ore producer. It is known as the Soudan Iron Formation. It occurs principally in the vicinity of Tower and Ely and consists of cherty iron carbonates, pyritic quartz rocks, ferruginous cherts, jaspilites and ore-bodies. The formation is usually folded into the Ely greenstone, as shown in Fig. 5. It sometimes is underlain by greenstone and sometimes by layers of slate. In places it occurs in belts between Ely greenstone on one side and Ogishke Conglomerate of the Lower Huronian on the other. The ore-bodies usually occur near the base of the iron formation and occur in synclinal troughs in the greenstone. They may be immediately underlain by altered greenstone, commonly known as soap rock or by thin layers of slate. At Soudan the ore-bodies are in part bottomed by greenstone and in part by porphyry associated with the greenstone.

The Agawa, or iron-bearing formation of the Lower Huronian, occurs chiefly in the eastern part of the district, on Hunter's Island, in Canada. It occurs in two belts on opposite sides of a syncline overlain by Knife slate and underlain by Ogishke slates and Conglomerates. The formation consists of ferruginous slates, ferruginous cherts, jaspilites, and iron-bearing carbonates. No ore-bodies have been found.

The Gunflint iron-bearing formation of the Upper Huronian is confined to the northeast part of the district west of Gunflint Lake. It consists of carbonate slates, ferruginous slates, and jaspilites, near Gunflint Lake, but southwest it grades off into amphibolitic and magnetic quartz rock, due to metamorphism of the Gabbro. No ore-bodies of much value have been discovered.

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

References for the Vermillion District.

1. Monograph XLV, U. S. G. S., by J. M. Clements.
2. 21st Ann. Rept. U. S. G. S., Pt. 3, by C. R. Van Hise.
3. Abstract: *Geol. Soc. Am. Bull.*, Vol. 14, p. 9, 1903. (Brief outline of the geology.)
4. Abstract: *Science*, New Ser., Vol. 16, p. 261, 1902.
5. Iron ore analyses. 18th Ann. Rept., V, U. S. G. S., p. 32; 19th Ann. Rept., VI, p. 49; 20th Ann. Rept., VI, p. 36.
6. A. I. M. E., Vol. 25, pp. 595–645, by H. L. Smyth and J. R. Finlay. (Chiefly relating to geological structure.)

CHAPTER V.

COPPER DEPOSITS.

The Butte District.—The State of Montana ranks second in the production of copper, producing, in 1907, 224,263,789 pounds of copper. Arizona ranks first with a total production, in 1907, of 256,778,437 pounds, and Michigan third, with a production of 219,131,503 pounds. Almost the entire production of Montana comes from the Butte District. The Butte District, situated in southwestern Montana, Silver Bow County, in the central part of the Rocky Mountain Region, has been made world-famous by its enormous copper- and silver-ore deposits. The formations shown in the Butte District are as follows:

Pleistocene		Alluvium and wash. East and southeast part of district.
Neocene	Lake beds	Sand, gravel and waterlaid tuffs. In the western part of district.
	Rhyolite..	Intrusive dikes, breccias and agglomerates. All dikes exposed have a N–S trend. All believed to be off-shoots from the Butte as a center of eruptive activity. Breccias consist of angular and in part rounded fragments held together in a matrix of fine rhyolite debris. They compose the greater part of the Butte. Breccia passes into agglomerate with increase in size of fragments.
	Rhyolite..	Extrusive. Chiefly in northwestern part of district. Fragmental in character. Clearly recognized as tuff or breccia due to explosive volcanic outbursts. From very thin to several hundred feet thick.

Post-Carboniferous.	*Quartz Porphyry.*—Occurs as dikes cutting the granite of Anaconda Hill. Pale green color and dotted with crystals of opaque white feldspar and large grains of glassy quartz. *Aplite.*—At Butte contains very little plagioclase feldspar and some small scattered grains of biotite, is white or cream colored, medium grained, of sugary texture, and bears a superficial resemblance to sandstone. Belongs to same general intrusion as the granite, but represents a differentiated, more siliceous material and fills fissures and contraction cracks in the granite. *Granite.*—Very basic. Dark colored, of coarsely and evenly granular appearance and resembles a coarse diorite. Much altered in all natural exposures. Few outcrops due to disintegration. Bordered by limestone, sandstone, shale and slate from the oldest Algonkian to late Cretaceous. Of the rocks actually cut and metamorphosed by the granite, the youngest containing recognizable fossils is Carboniferous.

The granites are younger than the Carboniferous rocks and possibly of Post-Cretaceous age. The rich ore-deposits of the district are intimately connected with fractures which cut the granite, aplite, and quartz porphyry. The fractures in the vicinity of Anaconda Hill have copper as the predominating mineral, while those to the north, west, and southwest are rich in silver. The veins of the district, both copper and silver veins, belong to three distinct systems. The oldest lodes have a general east-west course; the Parrot, Anaconda and Syndicate lodes being examples. Another set of fractures has a northwest-southeast course and has displaced the earlier veins. A still later set has a northeast course and has displaced both the earlier systems of veins. The first two systems are heavily mineralized and, in general, the earlier east-west system lacks the high silver contents of the northwest-southeast veins formed later. The last, or northeast-southwest, system of fractures shows a little ore, but the mineral mined is mainly the ore broken off from earlier deposits and included in the fault debris. The ore-bodies have also frequently been displaced by

either strike or dip faults. The strike faults are very numerous, the fault planes dipping about the same as the veins. Dip faults, while less numerous, are more easily recognized since they often displace the vein. The silver veins contain sulphide of silver, blende, pyrite, and a little galena. The gangue consists of quartz, with rhodonite and rhodochrosite, and shows marked banding and crustification in strong contrast to the structure of the copper veins. The copper minerals of the Butte ores consist chiefly of chalcocite, bornite, enargite, and cupriferous pyrite. The Butte District furnishes one of the best examples of secondary enrichment to be found. The copper lodes possess an upper oxidized zone extending down from 200 to 400 feet from the surface which contains less than 1 per cent. of copper, on the average, the value being chiefly in silver. This zone simply represents the original vein-filling, highly oxidized and leached. Below this is a rather ill-defined zone characterized by great values in the rich copper sulphides, bornite and chalcocite, associated with pyrite and chalcopyrite. Enormous amounts of copper glance were found in many of the veins, generally in the upper levels of the sulphide zone. They sometimes constituted solid masses fifteen feet or more in thickness.

References for Butte District.

1. **Butte Special Folio, No. 38, U. S. G. S., by W. H. Weed, S. F. Emmons and G. W. Tower.**
2. **Bull. 213, U. S. G. S., pp. 170–180, by W. H. Weed.**
3. **A. I. M. E., Vol. 16, pp. 54, 62.**
4. **A. I. M. E., Vol. 24, pp. 543, 548.**
5. ***Geol. Soc. Am. Bull.*, Vol. 14, pp. 269–276, by H. V. Winchell. (Chiefly on synthesis and genesis of chalcocite.)**
6. ***Can. Mg. Review*, Vol. 21, pp. 149–152, by William Braden. (Describes geological structure and ore deposition.)**
7. **Ores and Metals, Vol. 13, No. 10, pp. 15–16; No. 11, 19–20. (Describes mining, general geology and origin of veins and fissures.)**
8. **14th Ann. Rept. Mont. Inspector of Mines, pp. 26–33, by John Byrne. (General description of the district.)**

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

Lake Superior Copper District.—The succession of formations as given by A. C. Lane and A. E. Seaman from Lower Keweenawan to Ordovician is as follows:

Ordovician			St. Peter Calciferous ...	Sandstone: white, waterbearing in hollows of calciferous dolomite, but absent often. Buff and bluish dolomites, often sandy, with dolomitic white sandstones.
Cambrian or Primordial.	Neo-Cambrian Saratogan. (Potsdam)	Lake Superior.	Munising ...	Sandstone: white or light, waterbearing. 200 feet thick.
	Upper Keweenawan, perhaps...		Jacobsville Redstone Hiatus	Sandstone: red and brown and striped with streaks of red clay shale, conglomeritic where it laps upon older formations.
			Freda	Sandstone: red, with some felsitic and basic debris, and salt water.
	Mio-Cambrian.....		Nonesuch ...	Shales: dark, fissile beds, with dark basic fragments, and products of decomposition of lavas, copper-bearing. 350 to 600.

Lower Keweenawan, perhaps Eo-Cambrian.....	Copper Harbor.	Outer	Conglomerate: very heavy, red, with large rounded bowlders of all lower formations, including jaspilitic iron ores, agate amygdules, gabbro aplites, etc. 1,000 to 3,500.
		Lake Shore..	Traps: basaltic lavas, and at least one — the "Middle" — conglomerate. 1,800 to 400.
		Great	Conglomerate: very heavy, like the outer conglomerate. 2,200 to 340.
		Eagle River.	Group of basic lava flows, with frequent beds of sediment, Marvine's (*c*). 2,300 to 1,417.
		Ashbed	Group of basic lavas of the "ashbed" type with scoriaceous sediment and only 50 feet or so of conglomerate. Locally felsites. 1,456 to 2,400 ±. 50 sediment.
		Central Mine.	Group: mainly of lavas of the augitic ophite type, with frequent sediments. At the top is the "Mesnard epidote" and just beneath the heaviest flow, over 1,000 feet thick at times known as the Greenstone. Under this is the Allouez conglom. Marvine's No. 15. No. 13 is the Calumet and Hecla lode. The Kearsarge lode is shortly above 9. 3,823 to 25,000?
		Bohemian Range	Group: mainly of basic lavas but with intrusive and effusive felsites and coarse labradorite porphyrites also intrusive diabase dikes and gabbro and gabbro aplites. Also from 2 to 300 ft. sandstone. ? to 9,500 +. 500 sediment.

The Lake Superior District produced practically the entire output of copper in Michigan which, in 1907, was 219,131,503 pounds.

The rocks of the Keweenawan series occupy the greater part of Keweenaw Point and extend southwestward in a broad belt from 8 to 20 miles wide across northern Michigan and Wisconsin into Minnesota. They constitute the entire Minnesota shore of the lake from Duluth to Grand Portage Bay, and extend back in places 30 miles. They constitute a broad belt near Black and Nipigon Bays and all of Isle Royale and Michipicoten Island. In fact, they form a synclinal basin underlying the greater part of Lake Superior and, on Keweenaw Point, they form the south side of the basin dipping off steeply under the lake. The dip of the beds varies at different points along the strike. The dip, in general, decreases from the base of the series to the top; *e. g.*, at the Baltic mine, near the base of the series, the dip is as steep as 70°, while at the Atlantic mine, near the top of the series, the dip is only about 45°. At the Calumet and Hecla mine the dip is about 38°. As one would naturally expect from the synclinal structure the beds usually flatten out with depth. The copper of the district occurs principally in the native state. The lodes correspond closely to the dip of the formation, the copper filling in the openings of the upper portions of the amygdaloids, replacing many of the pebbles of the conglomerates and in places completely cementing the pebbles together. Besides occurring in lodes conforming with the dip of the series, some small quantities of copper occur along veins cutting the series transversely. Such veins are usually characterized by their sulphides and arsenides. Their ore-bodies are apt to pinch out and are frequently cut out abruptly by some massive flow. They probably represent a segregation subsequent to that of the great bodies of native copper. Both strike and dip faults exist in the district. The strike faults occur both parellel with the beds and also cutting across them at an angle. The dip faults often displace the lodes considerably.

Occurrence.—Throughout its deposits the copper exhibits a decidedly intimate connection with delessite, epidote and green earth silicates, containing a considerable percentage of peroxide of iron as a more or less essential constituent. While among the other silicates, viz., anal-

cite, laumonite, datolite and prehnite, only the last-named, which alone seems subject to the replacement of its aluminum by ferric oxide, is especially favored by copper. This association is so intimate that one is forced to the conclusion that there is a close genetic relation between the metallic state of the copper and the ferric condition of the iron oxide in the associated silicates. The intimate relation between native copper and ferric iron is shown also at the Nonesuch mine where the finely-divided copper impregnates the sandstone and often a small mass of copper encloses a small nucleus of magnetite.

Origin of the Native Copper.—The following is a quite generally accepted explanation. Copper is found in the less altered igneous rocks of the Keweenaw series in minute quantities in the form of a sulphide which is thought to be the original form of the metal, *i. e.*, when the lavas crystallized, the copper separated as copper sulphide or copper iron sulphide. The lavas were upturned by the formation of the Lake Superior syncline, denudation began and the formation of the copper deposits was inaugurated. Descending oxidizing waters transformed the copper sulphide into copper sulphates and took them into solution. The waters bearing sulphates of copper came in contact with solutions bearing ferrous salts or came in contact with ferrous compounds. The ferrous compounds reduced the oxidized compounds of copper to the native form. The upper surface of the amygdaloids and the belts of conglomerate formed trunk channels of circulation and furnished most favorable conditions for reduction and precipitation.

References for Lake Superior District.

1. Monograph V, U. S. G. S., by R. D. Irving.
2. *Eng. and Mg. Jour.*, Vol. 78, pp. 585–587, 625–627, 665–667, 705–706, 745–747, 785–787, 825–827, 865–867, 905–907, 945–950, 985–987.
3. Mich. Geol. Surv., Ann. Rept. for 1903, pp. 239–249, by Lane. (Theory of ore deposition.)
4. Mich. Geol. Surv., Ann. Rept. for 1903, pp. 251–270, by Lane. (Tamarack cross sections.)
5. *Mg. World*, 25, Aug. 18, 1906, p. 183.
6. A. I. M. E., Vol. 4, p. 110, by W. P. Blake. (Mass copper and mining methods.)
7. *Am. Jour. Sci.*, III, Vol. 2, pp. 188–198, by R. Pumpelly. (On paragenesis of copper.)

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

The Globe District. — The Globe district produced in round numbers 35,000,000 pounds of copper in 1907. This district is situated in the southeast central part of Arizona, including portions of Gila and Pinal Counties. It lies in the heart of the mountain region of Arizona, the Pinal range extending across the Globe Quadrangle from northwest to southeast. The formations occurring in the Quadrangle, in descending order, are as follows:

Quaternary	1. Alluvium. Sands and gravels along streams and in valleys. 2. Gila Conglomerate. Fluviatile deposits of irregularly bedded conglomerates, breccias, grits and tuffs. 3. Basalt. Surface flow intercalated in Gila conglomerate and small intrusive masses.
Tertiary	1. Whitetail Formation. Usually composed of subangular fragments of diabase and limestone. 2. Dacite. Surface flow and underlying tuff.
Triassic, Jurassic or Cretaceous..	1. Diorite Porphyry. Small sills and dikes intrusive in Globe limestone, Apache group, Madera diorite and diabase. 2. Diabase. Intrusive in Globe limestone and Apache group as thick sills and irregular masses.
Devonian and Carboniferous.	1. Globe Limestone. Hard, buff and gray limestone in beds ranging in thickness from 1 to 6 feet.
Cambrian	Apache Group. Chiefly quartzite with subordinate amounts of shale and conglomerate.
Pre-Cambrian ...	1. Pinal Schist. Muscovite or sericite schist of sedimentary origin with a little amphibolite schist and some incompletely altered grits. 2. Several varieties of granite intrusive into Pinal schist. Also diorite, metadiabase and monzonite intrusive into Pinal schist.

The principal mines of the Globe District are the Old Dominion and United Gold properties, the Summit Group and the Buffalo Mountain. The output for 1907 was about 35,000,000 pounds. In 1907 the production of the Globe District came mainly from the Old Dominion and United Globe mines. The chief production of the district

is from ore-bodies in limestone and shattered quartzite. The main ore-bodies lie on the southeast side of the great displacement which separates the sediments from the diabase and is known as the Old Dominion Fault. They

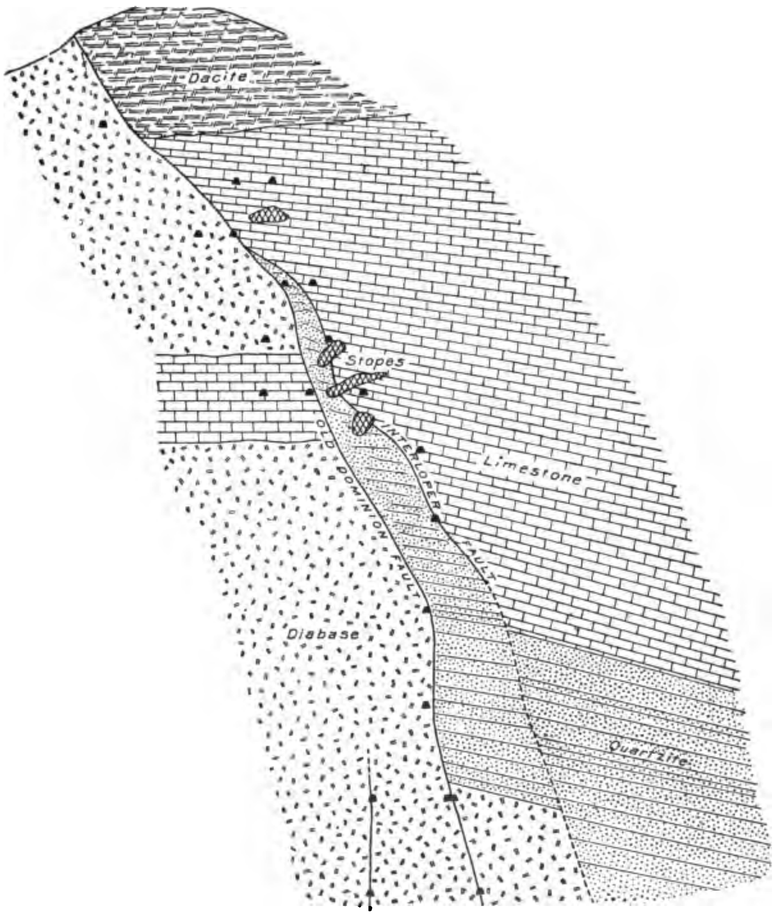

FIG. 6. Diagrammatic cross section through the Old Dominion mine, showing the occurrence of a mass of limestone in the diabase of the foot wall. (From U. S. Geological Survey, Professional Paper, No. 12, p. 138, Fig. 7.)

are found in the southern part of the Globe Hills within a radius of three or four miles from Globe. Although the same rocks as make up the Globe Hills occur in the north-

western part of the Globe Quadrangle and have been fissured and faulted similarly very little mineralization has occurred. To the south copper ores occur at the Black Warrier and Black Copper mines, in Webster and Gold gulches, and at the Geneva and Continental mines, and sufficient gold has been found in Lost and Gold gulches, both in small veins and in superficial gravels, to encourage prospecting. The ores of the Globe District may be classed as: (1) Free gold ores, (2) native silver or silver lead ores, and (3) cupriferous ores containing varying amounts of the precious metals. Classes (1) and (2) are unimportant and will not be considered. Those of class (3), according to their occurrence, are divided into: (1) Lodes, (2) masses in limestone, and (3) irregular mineralization of shattered or permeable rocks.

1. *Lodes.*—For the most part are simple fissure veins, and are mineralized post-diabase fault fissures. The post-dacite faults, so far as known, are unmineralized. Most lodes have northeast and southwest strikes and dips ranging from 40 to 90 degrees. As illustrations of lodes are the north vein in the diabase in the Old Dominion mine, the vein of the original Old Dominion mine in quartzite, and many others, particularly throughout the Globe Hills. The relations between the diabase limestone and quartzite are well shown in Fig. 6.

2. *Masses in Limestone.*—They are in close association with the Old Dominion fault. They are rudely lenticular in shape and lie roughly parallel with the nearly horizontal bedding of the Globe limestone. Some masses form the hanging wall of the Old Dominion fault and extend out irregularly 20 or 30 feet into the limestone. One such ore-mass in the Old Dominion mine was 200 feet long, 100 feet wide, and 60 feet thick.

3. *Irregular Mineralizations.*—These have contributed greatly to the output. One of the best examples is the shattered and mineralized belt of quartzite between the Old Dominion and Interloper faults. The ores of the district are largely oxidized. The first sulphide ore was shipped from the Summit mine in 1901. No sulphide ores have been found in the great ore-masses occurring in limestone. In the Old Dominion mine chalcocite was first encountered between 400 and 500 feet below the surface and continues downward at 900 feet. The deposits of the

Black Warrier, Geneva and Black Copper mines are those of chrysocolla replacing dacite tuff.

Near Liveoak Gulch the Schullze granite has been fissured and shattered and stained with carbonate and silicate of copper and workable deposits of chrysocolla have been exploited on a small scale in the Liveoak and Keystone mines. In general, there is more or less mineralization at several points in the Pinal schists close to the contact with the Schultze granite, but ore in workable quantity has not been discovered. Also in the diabase of Powers Gulch are a few small veins showing in croppings and shallow prospects principally of galena in rusty copper-stained quartz.

Genesis of the Ores.—The primary sulphide ores were probably deposited by ascending solutions of originally meteoric waters which had become charged with ore-forming constituents in the course of a shallow and devious underground circulation. Their metalliferous contents were probably derived from the deep-seated rocks of the region. A perfectly fresh, unfissured mass of diabase, so extensively intruded into the Carboniferous and older rocks was analyzed in the U. S. G. S. office and found to contain a trace of copper. Fissuring and mineralization followed the diabase intrusion and was probably the final stage of the same process. The original chalcopyrite was fractured and the fractured surfaces were coated with chalcocite showing that mineral to be of secondary origin. The process of sulphide enrichment appears to have worked downward, keeping 200 feet or more in advance of distinct oxidation. Chalcocite occurs as residual masses in the oxidized ores and as bunches in the pyrite below the limit of oxidation. The oxidized ores in great part occupy the places of formerly existing sulphides, the latter having been altered by descending solutions. The chrysocolla deposits of the Black Warrier, Geneva and Black Copper mines occurring as replacements of dacite tuffs, were, as shown by their structure, deposited directly as a hydrous silicate, and do not represent the alteration in place of former sulphides.

Age of the Original Sulphide Ores.—That the original ores are later than the diabase is established. That mineralization entirely preceded the dacite faulting is not so well

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

known, although it is strongly indicated by the following facts: (1) The mineralized fault fissures north of Globe either pass beneath the dacite flow without perceptibly faulting it or else they dislocate it to an extent incommensurate with their displacement of the older rocks. (2) No sulphide ore has yet been found in dacite. (3) The ore-bodies never extend irregularly into the dacite, but are separated from it by faults or else underlie it with every appearance of having been deposited, and at least partly oxidized before its eruption.

References to Globe District.

1. Folio No. 111, U. S. G. S., by F. L. Ransome.
2. Professional Paper No. 12, by F. L. Ransome.
3. A. I. M. E., Vol. 15, pp. 25–77, by A. F. Wendt. (Includes Bisbee and Clifton.)

Bisbee District.—The Bisbee district produced in 1907 about 110,000,000 pounds of copper. This district is in Cochise County, in the southeastern part of Arizona, and in the central part of the Mule Mountains, a few miles north of the Mexican line. The geological formations occurring in the district, in descending order, are as follows:

Quaternary	1. Fluviatile deposits, conglomerates with imperfectly rounded pebbles, gravels and sands.
Cretaceous	1. Cintura Formation. Beds of dull red shales, sandstones, grits and limestone lenses. 2. Mural Limestone. Thick-bedded gray limestone underlain by dark thin-bedded arenaceous limestone highly fossiliferous. 3. Morita Formation. Alternating beds of dark red arenaceous shale and sandstone with grits and limestone lenses. 4. Glance Conglomerate. Basal conglomerate of varying character. Pebbles imperfectly rounded and chiefly schists and limestone roughly bedded and contains some shale and sandstone.
Triassic or Jurassic.	1. Granite. Intrusive stock. 2. Granite Porphyry. With some rhyolite. Intrusive masses dikes and sills.

Carboniferous	1. Naco Limestone. Thin-bedded to thick-bedded, compact, non-magnesian, white, gray or pinkish limestone with subordinate shale. Fossils abundant.
	2. Escabrosa Limestone. Thick-bedded, non-magnesian, white, crinoidal limestone of granular texture.
Devonian	1. Martin Limestone. Dark gray. Compact, beds of moderate thickness with subordinate pink calcareous shale. Fossils abundant.
Cambrian	1. Abrigo Limestone. Thin-bedded, cherty, laminated, impure limestone with some calcareous shale, locally dolomitic, sandy in upper portion.
	2. Bolsa Quartzite. Basal conglomerate, thick-bedded, pebbly arkose grits and fine-grained vitreous quartzite.
Pre-Cambrian	1. Pinal Schist. Fine-grained, fissile quartz sericite schist. Probably metamorphosed sediments.

The chief producers in the Bisbee District in 1907 were the Copper Queen, Calumet and Arizona, Lake Superior and Pittsburg and Shattuck-Arizona companies. The district produced, to the end of 1902, 378,047,240 pounds of copper, entirely from the Copper Queen mine.

The principal ore-bodies lie south of and within a mile of Bisbee. They constitute a broad belt about 900 feet in width, which, beginning at a point about 2,000 feet southwest of the Czar shaft, continue northeastward, chiefly along the southeast side of the Czar fault to the Czar shaft, thence southeastward along the southwest side of the Dividend fault to the contact with the granite porphyry of Sacramento Hill. Here the ore-belt swings to the south, skirting the porphyry mass toward the Spray and Calumet and Arizona shafts. The relation of the belt of mines to the intrusive mass of porphyry is well illustrated in the accompanying photograph (Fig. 7). Whether it continues to skirt the porphyry to the east past the Gardner and Lowel shafts remains to be proved by underground work. The ores occur, for the most part, very irregularly as large masses in the Escabrosa and Naco limestone. The horizontal dimensions of these ore-

FIG. 7. Sacramento hill from the north showing the various mines in limestone around the intrusive mass of porphyry. (From U. S. Geological Survey, Professional Paper, No. 21, Plate XXIV, A.)

In the foreground is the old Copper Queen slag dump, beneath which and the lower ground just southwest of it occurred some of the largest ore bodies. On the right is the Holbrook shaft, and just above it in the picture, the Spray shaft. To the left of the spray is the Calumet and Arizona mine, and some distance to the left of that the Lowell mine. The mountains visible in the distance are in Mexico, the conical peak on the right being Mount Magellan, and the group on the left the Morita Hills.

bodies are usually much greater than the vertical. They usually lie parallel to the bedding planes of the inclosing limestone. On any single horizontal plane the dimensions of the ore-masses rarely exceed 150 by 200 feet, but in series of connected stopes, as for example, northeast of the Holbrook shaft in the Copper Queen mine, there was a practically continuous body of ore and ledge matter about 800 feet in length and 600 feet in width.

Bedding planes are not the only elements of geological structure that have influenced the deposition of ores. In the deeper workings of the principal mines, particularly of the Calumet and Arizona there is a well-marked tendency of the original pyritic impregnations to concentrate along minor zones of fissuring and shearing in the generally mineralized limestone. Pyrite, though strictly speaking, not an ore, is included with the ore minerals on account of its intimate chemical, physical and genetic relationship to them. It is the most abundant and widespread sulphide in the district. It is abundant in disseminated form in the intrusive porphyry mass of Sacramento Hill and in the schists to the east, but not in workable quantities. It is associated with the great ore-bodies in large quantities. In the upper levels it is often enclosed in envelopes of chalcocite and oxidized ore. In the lower workings it forms extensive bodies disseminated throughout the limestone. Only those portions containing chalcocite or chalcopyrite have proved workable. Chalcopyrite, unlike pyrite, is confined to the limestones entirely. Chalcocite is the most important sulphide in the district. It is found in the Copper Queen mine at various depths, but most abundantly in the irregular zones of rich sulphide ore that usually intervene between masses of lean pyrite and oxidized ore containing cuprite, native copper and carbonates. Chalcocite occurs as small masses and irregular veinlets scattered through the glance conglomerate which has excited much prospecting but developed no important ore-bodies. Native copper was common a few years ago near the bottom of the great oxidized ore-bodies in the Copper Queen mine, but is rather rare now. It is abundant in the Calumet and Arizona mines at the 950- and 1,050-foot levels. Malachite and azurite were abundant in the old workings of the Copper Queen mine, but at present are not very abundant.

Cuprite is an abundant and important constituent of the Bisbee ore-bodies. In the present workings of the Copper Queen mine the bulk of the cuprite occurs in earthy condition mixed with limonite.

Genesis of the Ores.—Two processes have operated to form the ores as they are now exploited in the Bisbee Quadrangle. (1) Metasomatic alteration, including pyrite mineralization, and (2) oxidation and its attendant phenomena of transportation and enrichment. In order to see clearly what was the probable cause of the original pyritic mineralization, several facts of occurrence must be taken into consideration which are as follows: Surrounding the mass of porphyry the limestone has been altered by metamorphism to a fine-grained aggregate consisting chiefly of quartz and calcite. The width of the zone is about 200 feet. Encircling this silicious zone is a zone of pale-green altered limestone in which pyrite, tremolite, diopside, grossularite and vesuvianite are the characteristic minerals.

Quartz is rare and calcite abundant. This zone grades off into unmetamorphosed limestones. The width of this zone averages about 1,000 feet. In general, the zone in which the metamorphic silicates are developed is that in which most of the ore-bodies are found. Metasomatic alteration has also affected the entire porphyry stock of Sacramento Hill. The alteration involved general recrystallization which, in some places, has obliterated the original porphyritic texture, in others left it faintly recognizable. The porphyry is impregnated with pyrite throughout; it being very abundant near the contact with limestone and nearly as abundant at the dump of the Copper King mine near the center of the porphyry mass. Metamorphism of the Pinal schist has produced a rock which the closest examination does not always distinguish from the altered porphyry. This also is impregnated with pyrite. The question arises as to the source of all this pyrite. The relation of the ores to the porphyry mass of Sacramento Hill justifies the conclusion that there is some genetic connection between them and the porphyry. The fact that the pyrite was formed at substantially the same time as the contact metamorphic minerals in the limestone is further evidence of such a genetic connection. Yet the granitic stock of Juniper Flat is connected with

no conspicuous mineralization and is not itself mineralized. There are many porphyry dikes in the district which cut limestone and do not produce mineralization. But these masses are all small. The only condition where a large mass of porphyry cuts limestone seems to be at Sacramento Hill, near to which the great ore-bodies occur. Small bodies of copper ore occur in the district which seems to show no connection with granite porphyry. Fissuring in limestone often means mineralization even without the presence of porphyry. The objection to regarding the metamorphism and mineralization as an ordinary case of contact action about an intrusive stock is two-fold. (1) The stock itself has been thoroughly altered and mineralized and could not have originally supplied from its own mass the large quantities of magnesia, sulphide of iron and other constituents introduced into the adjacent limestones. (2) The greater part at least, of the mineralization must have taken place after the porphyry had solidified. From the close relationship of the great ore-bodies to the Czar and Dividend faults and from the above facts of occurrence, it is concluded that the mineralization and metamorphism were effected by heated aqueous solution and the principal function of the porphyry consisted in supplying heat to such solutions as rose from great depths and thus determined the locus of chemical activity that resulted in the deposition of the ore. The source of ore-materials is not known. They may have risen through the Dividend fault from depths far below the bottom of the syncline of Paleozoic rocks. Again, they may have been collected by solutions moving through one or more of the Paleozoic limestones on their way down to the locus of deposition.

References for the Bisbee District.

1. Professional Paper No. 21, U. S. G. S., by F. L. Ransome.
2. Folio No. 112, U. S. G. S., by F. L. Ransome.
3. Bull. No. 213, U. S. G. S., pp. 149–157.
4. A. I. M. E., Vol. 29, p. 571, by James Douglas. (Good discussion of Copper Queen Mine.)
5. A. I. M. E., Vol. 15, pp. 25–77, by A. F. Wendt.

Clifton-Morenci District.—The Clifton-Morenci district produced, in 1907, 63,000,000 pounds of copper. This district is situated in the southeastern part of Arizona,

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

in the eastern part of Graham County. The town of Clifton is situated about 120 miles north of Bisbee, near the New Mexican line and not far from the Gila River. The geological succession is as follows:

Quaternary	Fluviatile sands and gravels. Gila conglomerate. Detritus roughly bedded and subangular.
Tertiary	1. Rhyolite. 2. Basalt. 3. Andesite.
Late Cretaceous or Early Tertiary....	Granite porphyry, quartz-monzonite-porphyry and diorite porphyry (connected by transitions).
Cretaceous	Pinkard formation (sandstone and shales). Several hundred ft.
Carboniferous	Modoc limestone—(heavy-bedded gray limestone sometimes Magnesian in lower part and contains Mississippian fossils). 180 ft.
Devonian	Morenci formation—(black clay shale, sometimes argillaceous limestone in lower part). 100 ft.
Ordovician	Longfellow formation—(heavy-bedded brown limestone, shale and siliceous in lower part; usually cherty and sometimes magnesian). 200 to 400 ft.
Cambrian?	Coronado quartzite — (quartzite sandstone, brown or red, usually with basal conglomerate). 200 ft.
Precambrian Granite.	

Masses of granite and dioritic porphyries were intruded into the older rocks after the deposition of the Cretaceous series, and form stocks, dikes, laccoliths and sheets. During latest Cretaceous or earliest Tertiary time all the previously existing rocks participated in an uplift and warping, succeeded by faulting. During Tertiary time enormous masses of basalt, rhyolite and andesite covered all the previously existing rocks. Erosion had sculptured the rock-masses of the district since early Tertiary time, and at many places has laid bare the older rocks by removal of the covering lavas. A part of the removed detritus—that carried away by the

streams during Quaternary time—still lies spread at the foot of the mountains, as coarse and roughly bedded deposits—the Gila conglomerate. This district ranks next to the Bisbee District as a copper-producing center, producing in 1907 63,000,000 pounds. Copper is the only metal produced in large quantities. The deposits were

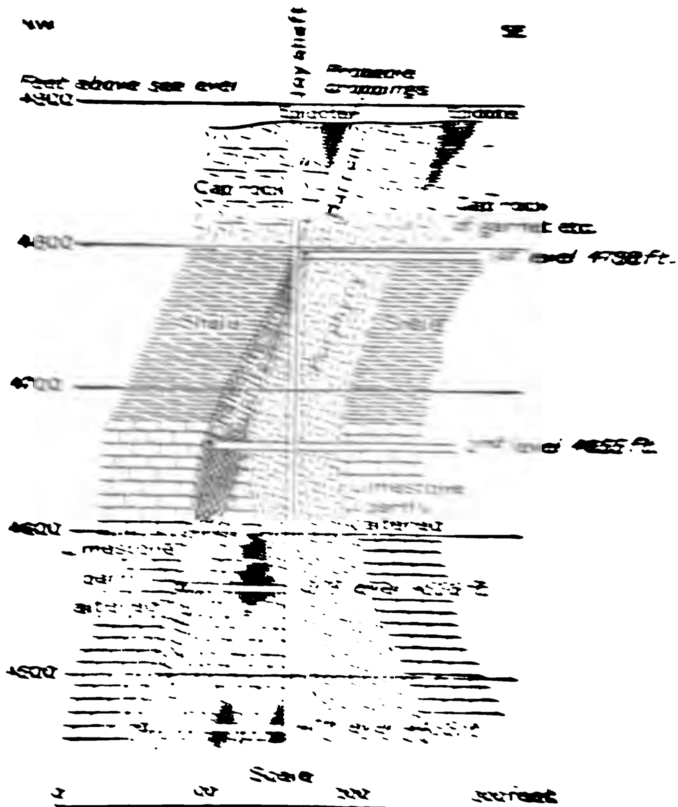

Fig. 8. Vertical cross section of the Joy shaft. From U. S. Geological Survey, Professional Paper No. 43, p. 188, Fig. 11.

discovered in 1872, but development was slow, owing to lack of transportation facilities. At present large bodies of low-grade ore are being mined. Two strong companies, the Detroit Copper Company and the Arizona Copper Company, have been the greatest producers since 1882. Since 1902 the Shannon Copper Company

has been added. The mines of the Detroit company are located at Morenci. Those of the Arizona company at Morenci and Metcalf, and those of the Shannon company at Metcalf. The copper deposits of the district may be grouped into two classes: (1) Contact metamorphic deposits, (2) fissure veins.

1. *Contact Metamorphic Deposits.*—There is no evidence of ore deposits having been formed in this district before the intrusion of porphyry. Where porphyry came in contact with granite or quartzite little alteration is observed, but at the contact with limestone or shale, extensive contact metamorphism took place, the pure limestone of the lower carboniferous, for a distance of several hundred feet from the contact, being converted into an almost solid mass of garnet. The relation of the porphyry to the limestone and shale and the resulting ore deposit is well illustrated by the accompanying Fig. 8.

The shales have suffered less, but near the porphyry are apt to contain epidote and other minerals. Wherever alteration has not masked the phenomena, magnetite, pyrite, chalcopyrite and zinc blende accompany, in various proportions, the contact metamorphic minerals, and are intergrown with them in such a way that the contact metamorphic origin of these ores appears beyond doubt. As to form, the ore deposits in limestone are often irregular but frequently assume a tabular shape, due to the accumulation of the minerals along certain planes of stratification or along the walls of dikes. The celebrated Longfellow mine is worked on one of these deposits, occurring as a funnel-shaped mass in the Ordovician limestone between two large porphyry dikes. Farther west, along the main porphyry contact, the Montezuma is encountered, and farther on the Detroit and Manganese Blue mines. Both of the latter mines were worked on tabular ore-bodies, occurring in horizons varying from Silurian to Lower Carboniferous. At Metcalf the Shannon mine contains several ore-bodies of similar origin. A fragment of the Paleozoic series outcropping on Shannon Mountain is cut by an extensive system of porphyry dikes. The accompanying Fig. 9 shows pre-Cambrian granite overlain successively by Cambrian quartzite, Ordovician limestone, Devonian shale and Caboniferous limestone. The entire mass has been faulted down and cut by

granite-porphyry dikes of Cretaceous or Tertiary age. Ore bodies are shown replacing Devonian shale, Carboniferous limestone and granite porphyry. In several horizons the limestones are greatly altered; the final product generally being copper carbonate, and limonite with some quartz. Where the ore-bodies are less altered the original character of the garnet, epidote, magnetite and sulphides is plainly seen. Oxidizing waters have very greatly altered the deposits in limestone. The sulphides have been converted into carbonates, and malachite and azurite are the most common ore minerals. Cuprite is common to Devonian shale. Chalcocite and other sulphides are almost entirely absent in limestone, and zinc blende has been carried away as zinc sulphate. Oxidation by surface waters, as at the Shannon mine, also diffused much copper as chalcocite, in some of the porphyry dikes and the deposit in the Metcalf mine consists chiefly of a body of extremely decomposed porphyry containing chalcocite and carbonates.

Fissure Veins.—At many places in the district the copper deposits consist of fissure veins cutting alike porphyry, granite and sedimentary rocks. From the available evidence these veins were formed a short time after the consolidation of the porphyry. In the lower levels the veins consist of pyrite, chalcopyrite and zinc blende. Between the leached croppings and the deep ores of pyrite and chalcopyrite is a more or less extensive zone of chalcopyrite or copper glance, deposited by secondary processes on the pyrite. The most important vein system is that extending from northeast to southwest through Copper Mountain. It is commonly known as the Humboldt Vein. The outcrop of the vein is barren, but at 200 feet contains chalcocite associated with pyrite. The seams are adjoined by decomposed porphyry richly impregnated with pyrite and chalcocite. Both the Arizona Copper Company and the Detroit Copper Company are working the low-grade bodies of chalcocite ore accompanying the veins. Malachite and azurite are not nearly so abundant as in the limestone deposits. The Coronado mine is formed on a fault fissure between granite and quartzite indicating a throw of at least 1,000 feet. The croppings contain carbonate and silicate which changes at slight depth to chalcocite. At the fissure veins on Markeen and

Copper King Mountain the granite is cut by a number of porphyry dikes. Along many of the dikes, movement and fissuring has taken place, and varying amounts of copper ores are distributed through the altered porphyry or through the granite near the dike. The most prominent deposit on this system of veins is the Copper King mine.

The main mass of porphyry between Morenci and Metcalf is strongly mineralized throughout. Fissure veins, though numerous in it, are neither persistent nor strong. The granite adjoining this porphyry is also often thoroughly altered and impregnated with pyrite and chalcopyrite.

Conditions of Ground Water.—Permanent water had not yet been encountered in any of the mines in 1904.

Depth of Oxidized Zone.—There is no well-defined plane expressing the depth of oxidation. Where solutions penetrated the altered porphyry or descended along fissures in limestone, the rocks are partly oxidized to a depth of 400 feet, but this is generally a maximum.

Genesis of the Ores.—The contact metamorphic effects of the porphyry have been described. The sulphides were shown to have been contemporaneous with the development of contact metamorphic minerals. The contact zone received additions of oxide of iron, silica, sulphur, copper and zinc, all of which are unknown in the sedimentary series away from the porphyry. It is believed that the porphyry magma contained all of the substances mentioned besides much water, sodic-chloride and ferric oxide. That large quantities of gaseous solutions dissolved in the magma were suddenly released by diminution of pressure as the magma reached higher levels and forced through the adjoining sedimentary beds. The formation of garnet indicates large gains of ferric oxide and silica. It has been shown that fissures and extensive shattering developed both in porphyry and altered sediments after the congealing of the magma, and that these fissures and seams were cemented by quartz, pyrite, chalcopyrite and zinc blende. As far as the metallic minerals is concerned there is a striking similarity between the veins connected with porphyry and the contact metamorphic deposits. A relationship is also clearly seen in the remarkable action of vein solutions on limestone, tremolite and diopside being formed in it by replacement. Iron and silica are

the main substances added during contact metamorphism as well as during the vein formation. The fluid inclusions in the vein quartz indicates that the veins were formed by aqueous solutions at a high temperature, for they contained various salts, in part those of heavy metals, especially iron which separated during the cooling of the crystallized quartz. This entirely eliminates the possibility of deposition by cold surface waters and points to deposition: (1) By atmospheric waters, heated by contact with the cooling porphyry, or (2) by ascending magmatic waters, or (3) by a mixture of both. In any case the metals must have been derived from the porphyry or from the deep-seated sources below the porphyry, for the presence of porphyry is the only common factor in all occurrences. It is probable that the fissuring which took place after the cooling opened vents of escape for magmatic waters under heavy pressure at lower levels, and that they ascended in these fissures, depositing the heavy metals and silica. It then remained for the surface waters, as erosion gradually exposed the deposits, to alter and enrich them to their present condition.

References for the Clifton-Morenci District.

1. Prof. Paper No. 43, U. S. G. S., by W. Lindgren.
2. Folio No. 129, U. S. G. S., by W. Lindgren.
3. A. I. M. E., Vol. 35, pp. 511–550, by W. Lindgren. (On ore genesis.)
4. *Eng. and Mg. Jour.*, Vol. 75, pp. 705–707, by W. Lindgren.
5. Bull. 213, U. S. G. S., pp. 133–140, by W. Lindgren.

The Bingham District.—This district is the leading copper-producing camp in Utah. It is situated in the north-central part of the state, in the Oquirrh Mountains, twenty miles southwest of Salt Lake City. The copper production of Utah in 1905 was estimated at 57,267,000 pounds, coming mainly from the copper mines of Bingham and Park City. The geological succession for the Bingham District is as follows:

Quaternary	1. Flood plain gravels, sands and clays. 2. Terrace gravels and sands.
Post Carboniferous....	1. Andesite, andesite porphyry and breccia. 2. Monzonite and monzonite porphyry.

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

Carboniferous	1. Phœnix limestone lentils.
	2. Petro limestone lentil.
	3. Yampa limestone lentil.
	4. Highland Boy limestone member.
	5. Commercial limestone member.
	6. Jordan limestone member.
	7. Lenox limestone member.
	8. Butterfield limestone member.
	9. Bingham quartzite.

The Bingham District includes an oblong area of about twenty-four square miles, which extends from the Jordan Valley on the east across the eastern slope of the Oquirrh range and the main divide to Pine Cañon on the western slope. Bingham Cañon with its tributaries drains the central and more important portion. The region has been the center of a complex succession of geological activities which have resulted in the deposition of valuable ore-bodies. The sedimentary country rock, including Carboniferous quartzite, metamorphosed limestone and calcareous shale has suffered extensive intrusion, intense fissuring and partial burial beneath an andesite flow. The ore-bodies are centered in the localities which have undergone the most intense intrusion and fissuring. The area occupied by the district lies in a shallow, flaring trough, or synclinal basin, that pitches northward. The general succession and structure has been interrupted by many irregular dikes and sills of porphyry, by laccolithic masses of monzonite and by several systems of persistant fissures. Two extensive areas of monzonite occur in the district, one at Upper Bingham and the other at the head of Bingham Cañon. The porphyry dikes and sills occur on the east and west of these masses. The andesite buries an old topography carved in the sediments and intrusives, and outcrops along the eastern slope of the range. After the epoch of igneous intrusion intense fracturing and fissuring occurred throughout the district at several distinct periods. Dominant fissures and fracture zones, which include the principal bodies of lead and silver ore, trend northeast-southwest. Distinctly later ones, of secondary importance, trend northwest-southeast. Numerous minor ones follow intermediate courses and movement has been repeated in a northeast-southwest direction. The displacements produced are frequently of a complex nature,

but rarely exceed 150 feet. Copper ore has been found in the form of flat lenses in metamorphosed limestone; lead and silver occur in fissures in all exposed types of rock; and copper, with accessory gold, is disseminated in grains throughout the monzonite. The low-grade copper-sulphide ore derived from bodies in limestones form the chief product of this district amounting to a daily output of approximately 2,000 tons, and is produced almost entirely by five great consolidated properties. Seven strike tunnels on Highland Boy ground has revealed large lenticular bodies of pyritic copper ore in fissured marble adjacent to intrusives.

The No. 1 shoot in this mine is not only the largest ore-body yet opened in Bingham, but is one of the largest single bodies of copper-iron ore in the world, that is known to have been deposited by replacement. Similar occurrences have been found, a short distance west, on the Boston Consolidated and Yampa properties. In Upper Bingham Cañon the Jordan limestone has been explored through the Old Jordan, Story and Niagara mines, and the Commercial limestone through the Commercial Northern Light and Colorado mines. On the eastern slope of the range the ore-bodies in these members have been exploited in the Brooklyn, Yosemite and Dalton and Lark group. In the above localities each of these metamorphosed limestones contain lenses of valuable copper ore that lie at different elevations within the limestone, roughly parallel to the bedding adjacent to fissures and intrusives. The ores which make up these lenses yield copper with accessory gold and silver. The richer ores occur within a distinct zone of sulphide enrichment and are composed chiefly of chalcocite, black oxide of copper, chalcopyrite and pyrite with a siliceous gangue. In some of them tellurium is associated with the black sulphide with proportionately high values of gold and silver. The copper content in the average sulphide ores is low, ranging from 2.25 to 4.5 per cent., but the accessory gold running from 10 cents to $1, and silver averaging from 2 to 5 ounces raise the price of ore per ton to from $11 to $15.

Fissures which cut these limestones, the igneous and quartzitic country rock to the south, and the Calcareous shales, intercalated with the quartzites, to the north, yield rich argentiferous lead ores. In Upper Bingham Cañon

the Galena, Neptune, Ashland, Silver Shield and several other fissures have been profitably worked. The accompanying Fig. 10 represents a mineralized zone of fracture along the contact between monzonite and quartzite. The fracture zone is traversed by rich pay streaks of lead and silver ore. In Muddy Fork, the Last Chance, Nast, Ferguson and Phœnix; in Markham Gulch, the Montezuma

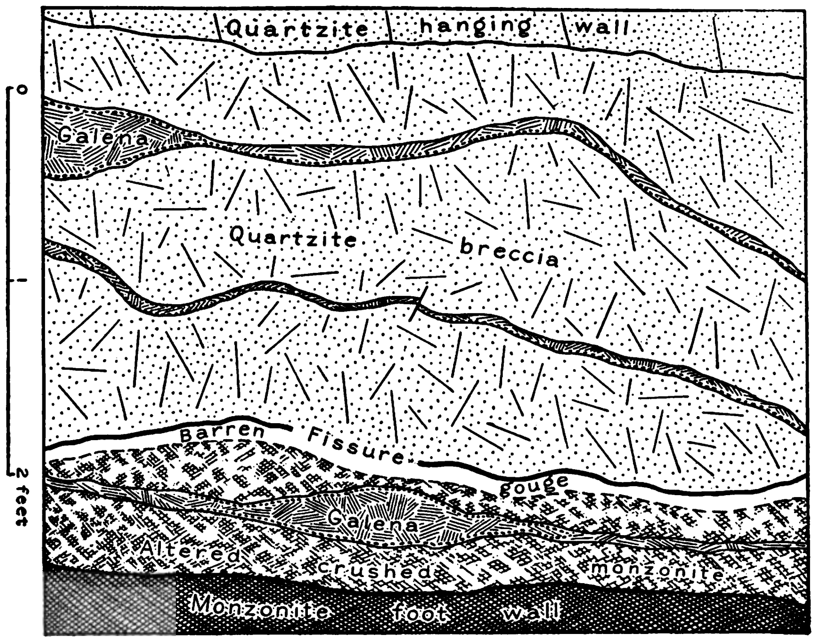

FIG. 10. Sketch showing structure of Silver Shield lode on northeast face of stope above No. 2 level, north of No. 6 raise. (From U. S. Geological Survey, Professional Paper, No. 38, p. 156, Fig. 4.)

and Julia Dean, and in Lower Bingham Cañon, the Winamuch, have also yielded profits. Both simple fissures and fracture zones cut all rock types indiscriminately and the included veins and lodes continue from one type to another, usually enlarging between limestone walls. These ores are composed mainly of galena, tetrahedrite, chalcopyrite, zinc blende and pyrite with a gangue of quartz, calcite, barite and rhodochrosite. The average content is approximately 45 per cent. Pb, 65 ounces Ag. Small amounts of gold and copper and 10 to 15 per cent. zinc.

Zinc blende has not been successfully saved. Concentration of the low-grade pyritic ore in igneous rock has recently been begun on a large scale at a reported profit. Placer mining which was an important industry in the early seventies has yielded a total of about $1,500,000; but, excepting a little intermittent gravel washing each year, it has been abandoned.

Genesis of the Ores.—In order to discuss the genesis of the ores at Bingham it is necessary to consider, separately, three classes of ores: (1) Ores disseminated through igneous rocks, (2) lode ores, (3) ores in limestone.

1. From the evidence in the field and from accordant detailed evidence it appears that the absence of pyrite and chalcopyrite in unparted, unaltered monzonite, their abundant occurrence on secondary parting planes, and their intimate association with sericitized feldspar, a biolite of possible secondary origin, and secondary quartz, show that they attained their present state considerably later than the intrusion and are, therefore, of secondary origin. It seems improbable that they were developed and deposited in their present state without the introduction of additional elements from without the intrusive mass. The observed stages of metasomatic alteration of magnetite culminating in the occurrence of minute, ill-defined coves of magnetite without secondary sulphides and finally in the total disappearance of magnetite, indicate that the chalcopyrite and pyrite was derived in part, at least, from the magnetite of the igneous rock.

Additional iron was doubtless derived from the original augite and biolite. The additional sulphur required was probably supplied from without, in the form of sulphurous gases. The immediate source of copper and gold remains unproved. If any of the pyrite is original, some of each of these other values might have been included as impurities but the large remainder can hardly be explained except by subsequent introduction from without.

2. Regarding structure, the lode ores show a group of relatively parallel pay streaks, each with marked banded distribution of minerals, entirely unlike the granular disseminated copper ore in porphyry, or the massive lenses of copper ore in limestone. The restriction of these lodes to a single set of zones of strong fracturing, the continuity of the breaks regardless of their contents, the unity of the pay streaks, and finally the roughly banded structure,

signify that the fracture existed before ore deposition and offered partially opened spaces, favorable pathways for the mineral-bearing agent and suitable areas for ore deposition. The character of the walls, however, show that replacement took place along the wall of the opening to some extent. The chemical character of the transporting solution is indicated by the chemical composition of the deposits, and the character of the alteration of the wall rock. The increasing richness where veins cross limestore or carbonaceous shale, show that calcareous and carbonaceous material had a precipitating influence on the solutions. In summarizing Mr. J. M. Boutwell says: "It appears that heated, aqueous, mineral-bearing solution, rich in CO_2 and K_2O rose along strong notheast-southwest fracture zones, altered their walls by adding quartz to quartzite, impregnating marble with metallic sulphides and specularite and silicifying, sericitizing, and impregnating monzonite with metallic sulphides and depositing the lode ores in largest volume between calcareous and carbonacious walls, mainly by filling, partially by replacement."

3. *Copper Deposits in Limestone.*—Regarding the origin of copper deposits Mr. Boutwell also says: "The extensive contact metamorphism in this district, the occurrence of gangue minerals characteristic of contact deposits in intimate association with ore minerals, the restriction of the copper shoots in limestone to areas of contact metamorphism, the content of some gold and silver in the sulphides, and the association of oxide of iron with the sulphides of copper, suggest strongly a causal relationship between intrusives and deposition of copper ore. . . . It is probable that the principal source of the copper ore in limestone was the magma of the intrusive, that the mineral elements were transported by the intrusives and by the thermal solutions and vapors emitted from both their superficial and deeper portions and that ore was deposited by molecular replacement of a metamorphosed, at least partially marmorized and silicified country rock."

References for the Bingham District.

1. Professional Paper No. 38, U. S. G. S., by J. M. Boutwell, Arthur Keith and S. F. Emmons.
2. Bull. 213, U. S. G. S., pp. 105–122, by J. M. Boutwell.

3. Bull. 260, U. S. G. S., pp. 236–241, by J. M. Boutwell.
4. *Eng. and Mg. Jour.*, Vol. 79, pp. 1176–1178, by J. M. Boutwell.
5. A. I. M. E., Vol. 30, p. 194. (Chiefly regarding the Highland Boy Mine.)

DATA RELATING TO PRODUCTION AND CHARACTER OF COPPER ORES FOR 1907.

(Taken from Mineral Resources of the U. S. for 1907.)

Butte District, Montana.

Chief production came from the mines of the Amalgamated, the North Butte, the Butte Coalition, the Clark, Pittsburg and Montana Companies. Production for Montana in 1907 amounted to 224,263,789 pounds. Nearly the entire production came from Butte. About 90 per cent. of the production for 1907 came from chalcocite. Enargite furnished the bulk of the remainder. Bornite and chalcopyrite furnished a little and a comparatively small quantity came from the oxidized ores from the eastern part of the camp.

Owing to the great quantity of concentrating ores of low-grade, comprising about 85 per cent. of the total ore treated during 1907 the average copper yield is low, approximately 2.75 per cent. High loss attending a close separation of ore and gangue and the considerable percentage of chalcocite-coated pyrite in the ore permit only a low concentration, the average being close to 3 into 1. Concentrating ores yielding about 2.3 per cent. copper supplied over 70 per cent. of the total output, the remainder coming from smelting ores, which averaged about 5.2 per cent. yield. The average in silver for 1907 was about 2.3 ounces per ton of ore. Gold yielded 0.014 ounces per ton of ore. Precious metals reduced the cost of production of copper by about 2.2 cents per pound. The recovery of arsenic from the enargite ores as practised at the Washoe Smelter is also a source of revenue.

Exploration for the extension of profitable ground to the north, south and east has been attended with little success. The most important developments continue to be in depth. The fine showing in the bottom of the North Butte and the continuance of good ore in the 2,600 foot level of the Anaconda mines are the most noteworthy feature of the year.

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

Bisbee District, Arizona.

Arizona produced in 1907 256,778,437 pounds of blister copper and ranked first among the copper-producing states. Of this total production the Bisbee District produced 110 million pounds. The ores consist mainly of carbonates, oxides, chalcocite, chalcopyrite and pyrite, all being in places more or less intimately mixed. Native copper is present also in many localities and in some stopes has been very abundant. As nearly as can be learned between 35 and 50 per cent. of the copper mined in 1907 was contained in the sulphides, chiefly chalcocite, and practically the whole of the remainder was carried by the oxidized minerals. The percentage of sulphide ore mined is increasing. From the standpoint of total production since the district was discovered, the Bisbee District is undoubtedly the richest of the great copper camps of the country. The ore mined to date is estimated to have yielded 8 per cent. copper, although in recent years it has fallen considerably below that amount. Calumet and Arizona ore in 1907 yielded 5.85 per cent. Superior and Pittsburg ores yielded 3.69 per cent. in 1907. All the ore mined in the district is rich enough to smelt, and no concentration is practiced. The values in gold and silver are rather low. In 1907 the yield of gold and silver per ton of copper was $13.74 for the Calumet and Arizona Company and $6.90 for the Superior and Pittsburg Company. The most important feature of the year is the development on the lower levels of the Calumet and Arizona workings of bodies of pyrite, chalcopyrite, and bornite ore, little enriched, and carrying good copper values. The ore bodies worked at present lie mostly between depths of 400 and 1,400 feet, the ore being deeper toward the southeast. The known ore bodies near the surface are practically exhausted. The Bisbee ores are of wide range in composition, and are virtually self-fluxing and are smelted economically.

Morenci District, Arizona.

This district produced in 1907 63,000,000 pounds of copper. The greater part of the production came from the mines of the Arizona, Detroit and Shannon companies. With the exception of some of the ores of Shannon Mountain, the old shallow bodies of high-grade oxidized ore

derived from contact-metamorphic displacement of limestone have been exhausted. A great part of the production came from large disseminated bodies and stockworks of chalcocite along shattered zones in altered porphyry. The profitable ores in places change in depth to lean pyritic ores. The bulk of the ores are of low tenor in copper; nearly 90 per cent. of them are milled with a concentration of about 6 into 1. The average yield of blister copper from these concentrating ores was slightly over 2 per cent. in 1907. The smelting ores which include the richer chalcocite ores and the oxidized ores mined by the Shannon Company, gave a yield of about 5 per cent. The content in gold and silver is very low, running about $3 per ton. With the exception of the Coronado Mine few profitable ore bodies occur at a greater depth than 400 feet. This district differs from that of Bisbee and Jerome where the ores are of smelting grade, and is dependent upon the capacity of its concentrating mills.

Globe District, Arizona.

This district produced in 1907 35,000,000 pounds of blister copper. The output was derived chiefly from the Old Dominion and United Globe mines. The Globe ores have long been known to be of high-grade, and some of the mines are still shipping ores of an average content considerably over 5 per cent. The increase in quantity of low-grade concentrating ores in the United Globe and Old Dominion mines has lowered the tenor for the district so that the average yield for all the ores in 1907 was a little over 4 per cent. A little more than one third of the ore treated in 1907 was concentrated on an average about 3.5 into 1. Sixty per cent. of the 1907 output was derived from sulphides, chiefly chalcocite. Ore of this class will undoubtedly soon become the principal ore of the district. The greater part of the ore from the outlying mines is oxidized and much of it consists chiefly of chrysocolla. The gold and silver contents of the ore are very low, and the average yield per pound of copper is only about one half cent. Most of the workings are not deep. The deepest shaft of the camp is only about 1,200 feet. Globe ores have long been at a disadvantage because of their high silica and lack of sulphur. Sulphides from outside

had to be brought in, and favorable smelting charges by the local works have been impossible on much of the oxidized siliceous ore from mines in the district. Bisbee, Arizona, and Nacozari, Mexico, supplied sulphide ores in 1907, while considerable siliceous ore of the district went to the Douglas, El Paso, and Cananea smelters, chiefly for converter lining. By the middle of 1907, however, the quantity of sulphide ores from the Old Dominion and United Globe mines was about sufficient to give proper results in the furnaces, and importations have now practically ceased.

Jerome District, Arizona.

The production of blister copper in 1907 was 33 million pounds. The United Verde Copper Company is responsible for practically the entire output. The United Verde Ore body occupies a zone of shearing so intense that the containing rock, a rather basic porphyry, has been converted into a schist. Pyrite, chalcopyrite and some zinc blende, with varying amounts of quartz, have in places partially or completely replaced this schist, and in other places the schist is injected by veinlets and stringers of sulphides and others of quartz. As a rule the more massive sulphide ore contains more iron and zinc, while that consisting of alternating bands of sulphide and schist—the so-called "slaty" ore—carries a much higher proportion of chalcopyrite. The ores are undoubtedly of Pre-Cambrian age, like the inclosing rocks, and are wholly independent of the Devonian sediment which almost overlies the deposit. Almost the entire output in 1907 came from sulphide ores, but a little oxidized ore, rather high in gold, added to the production. The ores mined are all of smelting grade, and carry a high percentage of copper. The average yield in 1907 having been considerably above that of the Bisbee camp and much higher than that of the other large pyritic deposits such as occur at Bingham, Utah, Shasta County, Cal., and Ducktown, Tenn.

Bingham District, Utah.

This district produced in 1907 about 47 million pounds of copper. The ore deposits which up to the present have been most productive are large replacement bodies of

heavy pyritic ore in limestone near the contact of a porphyry. Chalcopyrite is present in the pyrite, and gives the ore its value in copper. The ores are mostly massive and comparatively impervious, and oxidation with accompanying secondary enrichment has proceeded to relatively shallow depths. At present practically all the copper from the deposits of this type are derived from the primary pyritic ore. The second type of ore deposit has only recently been actively exploited, but its contribution to the district's output in 1907 was considerable, and is certain, at an early date, greatly to increase the output of the camp. These ores are mainly disseminations in silicified porphyry of pyrite and chalcopyrite, either coated or completely replaced by secondary chalcocite. The immense deposit being worked jointly by the Utah Copper and the Boston Consolidated companies is a disseminated deposit, which appears independent of important fissures and fractures. In the Ohio Copper Company's property the secondary ore is more confined to definite fractures and veinlets, and where these are in quartzite the copper occurs chiefly as cuprite and native, as at Globe, Ariz. By tunnels and diamond drilling, these great deposits have been proven to extend several hundred feet below the surface. In copper content the ores of the pyritic replacements of limestone vary greatly. The average recovery of copper in 1907 from all these replacement ores, of which about 605,000 tons were treated, was lower than for previous years, and was about 2.3 per cent., though the range of copper was from less than 1 per cent. to over 3 per cent., and of precious metals from \$0.65 to \$3.10 per ton. The gold and silver ores as well as the lead ores encountered in some abundance in certain of the mines aid in reducing the cost of copper production. The great disseminated chalcocite deposits occurring in porphyry have been estimated by very extensive sampling to contain an average of between 1.5 and 2 per cent. copper. The yield from concentrates smelted in 1907, representing over 700,000 tons of ore, was about 1.2 per cent. copper, 17 cents gold, and 5 cents silver per ton, or nearly one cent in precious metals per pound of copper.

The foregoing districts including the Lake Superior district, the Butte District, the Bisbee District, the Clifton

Morenci District, the Globe District and the Bingham District, represented approximately 80.5 per cent. of the total production of blister copper in the United States in 1907. Without going into detail with reference to the distribution of copper throughout the United States, brief mention will be made concerning three other rather well known districts, which together produced approximately 10.5 per cent. of the entire output for 1907. These districts are the Jerome District, Arizona; the Shasta Region in northern California, and the Ducktown region in south-eastern Tennessee. The character of the ore body and the associated rocks in the Jerome District have been already referred to.

Shasta District, California.

The Shasta Region in northern California, which lies near Sacramento and Pitt rivers, north of Redding, produced in 1907 about 28 million pounds of blister copper. This production came from three companies, the Mammoth, the Mountain and the Great Western. The typical ore of the region occurs as large bodies in intensely crushed granitic porphyries and locally in adjoining shales. It is a massive sulphide made up of varying proportions of pyrite and zinc blende with chalcopyrite in comparatively small amount, and ranges from less than 1 to over 8 per cent. copper as mined. The secondary zone, which was wonderfully productive of copper and silver at the Iron Mountain and Bully Hill mines has been exhausted, and at the other mines is either of little importance or practically absent. The ores smelted in 1907 yielded approximately 3 per cent. copper. The yield per ton in gold was about $1.30 and in silver 2.1 ounces, which combined are equivalent to 4.5 cents per pound of copper. Most of the ore bodies thus far discovered are developed by workings not more than 500 feet deep, but the Great Western workings, in the Afterthought District, exceed this depth and in the Bully Hill district the lowest level is about 900 feet below the outcrop. Owing to the rugged topography tunnels afford easy access to the ore bodies, but in a few places winzes from these tunnels are required. Open cutting is employed in part at the Balaklala and the Afterthought mines.

References for the Shasta District.

1. Folio No. 138, U. S. G. S., by J. S. Diller.
2. *Eng. and Mg. Jour.*, Vol. 73, pp. 857–858, by J. S. Diller.
3. *Mg. and Sci. Press*, Vol. 85, pp. 62, 72, by J. S. Diller. (On the occurrence of copper ores.)
4. Bull. No. 213, U. S. G. S., pp. 123–132, by J. S. Diller.
5. Bull. 23, Cal. State Mg. Bureau, 275, pp. and map, by L. E. Aubury.

Ducktown District, Tennessee.

The production of this district in 1907 was 19,475,119 pounds of blister copper. The ores are low grade, and lie as great lenticular masses of sulphides parallel to the steeply inclined foliation of schists. Both the ores and the schists are probably of pre-Cambrian age. The ore minerals are predominantly phyrrhotite with chalcopyrite and pyrite. Oxidation of the upper portion of these deposits produced heavy gossan, underlain by rich secondary chalcocite ores, long ago exhausted. The entire output now comes from primary ores. The ores are low grade. The average recovery in 1907 having been about 35.4 pounds per ton or 1.77 per cent., a slight increase over the yield in 1906. Precious-metal values are also low, and part of the copper is sold as pig copper without refining. The blister which in 1907 was refined in this country by electrolysis amounted to a little less than half the total output for the year, and such part of it as was not mixed with the product of custom ores yielded precious metals to the value of 44 cents per pound, .04 per cent. of this being gold. The ore bodies as yet developed lie within a few hundred feet of the surface, the deepest shaft being a little over 700 feet. The steeply inclined attitude of the deposits and the great strength of the schist walls permit great stopes to be opened and ores extracted by a system of underground quarrying without the use of timber.

References for the Ducktown District.

1. A. I. M. E., Vol. 31, pp. 244–265, by J. F. Kemp.
2. A. I. M. E., Vol. 30, pp. 449–504, by W. H. Weed.
3. A. I. M. E., Vol. 25, pp. 173–245.

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

CHAPTER VI

LEAD AND ZINC DEPOSITS.

Southwestern Wisconsin Lead and Zinc District.—The following brief description is taken chiefly from Wisconsin Geological and Natural History Surey Bulletin No. 9, 103 pp., by U. S. Grant. The second most important zinc district in the Mississippi Valley is that occupying southwestern Wisconsin and adjacent portions of Illinois and Iowa. It ranks next to the Joplin district, producing, in 1906, 42,130 tons of zinc ore and 2,100 tons of lead ore. The succession of formations in the district is as follows:

Quaternary ...	Residual soil, alluvium and loess............	7 ft.
Silurian	Niagara dolomite	100 ft.
Ordovician ...	Maquoketa or Hudson River shale...........	160 ft.
	Galena dolomite	230 ft.
	Platteville or Trenton limestone and dolomite.	55 ft.
	St. Peter's sandstone	70 ft.
	Lower Magnesian dolomite with some sandstone	200 ft.
Cambrian	Potsdam sandstone with some shale and dolomite	700 ft.
Pre-Cambrian.	Various metamorphosed sediments and igneous rocks.	

The first mining in this district was done on the site of the present city of Dubuque, Iowa, in 1788 by Julian Dubuque, who obtained from the Indians land on which lead had been discovered a few years previously. In 1830 mining had become quite general near Dubuque, Iowa, and Galena, Illinois, and also in southwestern Wisconsin. From that time to the present mining has been carried on continuously. Up to forty years ago lead only was mined, zinc being of little value. The production of zinc has increased, however with demand until now the district is far more important as a producer of zinc. The only rocks exposed in the district belong to the Paleozoic

series, no igneous or metamorphic rocks occurring at the surface. Galena dolomite is exposed at the surface throughout the greater part of the district. Throughout the district as a whole the rocks have a gentle inclination toward the south-southwest. The gentle dip averages about 20 feet per mile. Aside from the general inclination to the south-southwest the district is crossed by a series of gentle rolls of the strata whose axes run approximately east and west. Some of the folds have a pitch either to the east or west showing that the district has been compressed by a force acting in an east-west direction as well as by one acting in a general north-south direction. All the formations in the district with the exception of the St. Peters sandstone and Maquoketa shale, very commonly show pronounced series of joints. These are especially well developed in the massive Galena dolomite. There are several directions of jointing; but the main joints are practically vertical. The most pronounced system strikes a few degrees north of west. They are called by the miners "east and wests." Crossing this are other less important systems, the one more commonly developed striking a few degrees east of north, commonly called "north and souths." There are also quartering crevices commonly called by the miners "Two o'clocks" or "ten o'clocks." In addition to the vertical joints there occurs, especially in the vicinity of the mines, a series of pitching joints. These usually have the same strike as the main vertical joints and are confined to the smaller synclines. These dipping joints which are inclined at from 20° to 60° to the horizontal are especially important in some of the mines, for in these occur the deposits known as "pitches."

Ores and Associated Minerals.—The minerals of this district are not very numerous, comprising only a few of the commoner forms. The most important minerals are galenite, sphalerite, smithsonite, marcasite and calcite. Certain other minerals are of considerable interest in a study of the ore deposits themselves. They are cerussite, anglesite, chalcopyrite, malachite, azurite, wad, selenite, barite, sulphur and quartz.

Ore Deposits.—Minor amounts of lead and zinc have been found in all the formations of the district from Niagara limestone down to Cambrian sandstone, but the pro-

ductive ore bodies are confined to the Galena and Platteville limestones. The deposits occur in all the divisions of the Galena, but the most important deposits, *i. e.,* the peculiar flats and pitches, and the disseminated deposits occur at or near the base of this formation. Some of the crevice deposits run as high as the upper half and even close to the top of the galena limestone. In the Platteville limestone the ore is confined to the upper member of the formation and occurs most commonly in the shale immediately underlying the oil rock, in the main glass rock beds and at times near the base of the glass rock, associated with some narrow bands of oil rock. Such is the condition at the Mason Mine near Linden.

Form of Deposits.—The deposits may be grouped into two divisions, according to form as follows: (1) Those which occur in cracks or crevices in the rocks, and are in the nature of vein deposits. They include vertical crevices and flats and pitches. (2) Those which are disseminated in small particles throughout the rock and which do not occur in fissures which were once, or are now open. The crevice deposits occur in fissures which have usually been enlarged by solution before the ores were deposited, but the ore minerals seem to have been in all cases deposited in open cavities and are not in the nature of replacements. The main ores have come from the east-west crevices, but it frequently occurs that where there is a crossing of crevices particularly rich deposits occur. The term "range" is applied by the miners to a crevice or a series of parallel crevices close together which carry ore. An example of several ranges occurring near together is shown at the Hazel Green mine near Hazel Green. Ore deposits extending away from the vertical crevices horizontally along certain beds are usually called "openings." The openings are common to the upper half of the Galena limestone, while the "flats and pitches" are in the main confined to the lower part of the formation. The pitches are the mineralized pitching joints, while the flats are mineralized horizontal openings running along the bedding. At times such a series of flats and pitches may be from 100 to 200 feet across, and where the flats run back from the pitches into the foot wall, there is a considerable mass of rock extending from one pitch to the other, which can be mined out. Such is the case at the Hoskin and

Kennedy mines near Hazel Green. In certain cases, as at the Enterprise mine at Platteville, there are secondary pitches which have directions very different from those of the main pitches. Associated with the crevice deposits are others called "Honey Comb" deposits. Under such are included certain apparently brecciated and very porous parts of the Galena limestone, in which the cavities have been more or less filled with ores. The openings are in part due to brecciation and in part to solution. This class of deposit is shown at the Oldenburg mine near Galena, at the Strawberry Blonde mine at Strawbridge, and in parts of the Enterprise mine at Platteville, the Hazel Green mine near Hazel Green and the Dawson mine near Benton.

The disseminated deposits are horizons in the rock which have been more or less permeated by crystals of sphalerite or galena. The particular horizons for these disseminated deposits are: (1) Thin beds of limestone or dolomite which immediately overlie the oil rock; (2) in the oil rock itself; (3) in the clay bed, which in some of the mines immediately underlies the oil rock, and (4) at the base of the main glass rock beds associated with some thin layers of oil rock. Deposits of this character are especially well developed west and south of Platteville at the Graham and Stevens, the Klondike, the Tippecanoe and the Capitola mines. As a general rule the disseminated deposits carry less marcasite than do the flats and pitches and the vertical crevices.

Order of Depositioin.—In the crevice deposits the usual order of deposition is as follows, beginning from the wall and going to the center of the vein: (1) Marcasite, (2) sphalerite, at times containing some galena, (3) galena; (4) calcite, (5) barite. All five are not always represented but almost invariably the wall rock is coated with marcasite and outside of this is a layer of sphalerite with or without galena. Sometimes a second period of marcasite deposition has taken place and rarely all of the metallic sulphides are mingled together.

Change of Ores in Depth.—There is also a marked vertical arrangement of the ores. Three distinct zones are noticeable. At the top and near the surface of the ground there is a zone containing large crystals and masses of galena. This zone is above the level of the ground water and is

being continually lowered by erosion. Below this is a zone in which smithsonite is the important ore. This extends down to, and in some cases a few feet below, the level of ground water. The third zone below the level of ground water is essentially a sphalerite zone. While each zone is characterized by its own peculiar mineral the galena of the first zone extends down into the second zone and it is found, to some extent, in the zone of sphalerite especially near the top. Here it often coats sphalerite in large crystals. It decreases with depth and, near the bottom of the sphaleric zone, exists intimately mixed with sphalerite. The smithsonite of the whole district is an alteration product from original sphalerite. The alteration has taken place everywhere above the level of ground water. This level varies from ten feet, in the valleys, to over one hundred feet on the highlands.

Relation of Ore Deposits to Structure.—Detailed investigation has shown that many of the disseminated deposits as well as many of the flat and pitch deposits bear a close relation to the folding. They lie in synclinal troughs or basins. It is expected that more detailed mining exploration will show a still closer relationship between the great deposits and the structural basins.

Origin of the Ores.—It is now commonly believed by geologists that the ore deposits of this district are derived entirely from the country rock; that is, mainly from the galena limestone. There is no evidence whatever that the ores have been brought up from deeper-seated areas as is the case in many mining districts. The ore substances were, in all probability, brought in solution from the crystalline rocks existing to the north and were precipitated by some means, possibly by plant life in the Ordovician ocean. The ore deposits as they exist today are due to the circulation of waters in the Ordovician rocks; these waters have dissolved the minute particles of these metallic substances scattered through the rocks and have redeposited them in their present position. The ore deposits are, in many cases, intimately related to structural basins. The galena limestone is floored practically by impervious layers, *i. e.*, the oil rock and the shale just below it. These basins have acted as channels for water circulation. The organic matter in the oil rock has played an important rôle in the precipitation of the metallic

substances held in solution, thus producing the disseminated deposits.

References for Southwestern Wisconsin Lead and Zinc District.

1. *Wis. Geol. and Nat. History Survey Bull.*, No. 9, pp. 103, by U. S. Grant.
2. *Econ. Geol.*, Vol. 1, pp. 233–242, by U. S. Grant.
3. Bull. No. 260, U. S. G. S., pp. 304–310, by U. S. Grant.
4. *Inst. Mg. Engrs. (England) Trans.*, Vol. 23, pp. 376–434.
5. "Geology of Wisconsin," Vol. IV, Pt. IV, p. 377, by T. C. Chamberlain.

Joplin Lead and Zinc District.—The following is a brief summary of the facts brought out in Folio No. 148, U. S. G. S., by W. S. Tangier Smith and C. E. Siebenthal. This district lies mainly in southwest Missouri and comprises portions of Jasper and Newton Counties in that State and also a portion of Cherokee County, Kansas. This district is by far the most important zinc producer in the Mississippi Valley. The production of 1906 of zinc ore from the Joplin District, including a small production from southeast Missouri, was 283,500 tons. The production of lead ore for the same year was 39,189 tons. The geology of the district is comparatively simple. The succession for the district is as shown on page 105.

The district will first be considered with reference to certain structural features.

Folding.—Structurally, as well as topographically, the district culminates in the southeastern portion from which the rocks incline gently northward, northwestward and westward at a somewhat higher angle than the surface slope. This dip carries the Boone formation below drainage a short distance west of Spring River. The limestone shows a series of domes and depressions with diameters varying from half a mile to two miles or more, and differential elevations varying from 10 to 30 or 40 feet. These features are due rather to deformation than to deposition alone. The principal orogenic feature of the district is the pronounced anticline which enters the district from the south just east of Shoal Creek and bears northwestward to the vicinity of Waco. The inequalities in elevation arising from this orogenic movement amounted to 150 to 200 feet. It is much steeper on the western limb than on the eastern.

SUPPLEMENTARY NOTES.

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Carboniferous.	Pennsylvanian	Cherokee formation. Drab to black shale and gray to buff sandstone with occasional beds of coal. Thickness 150 ft. +.	
		Unconformity.	
	Mississippian.	1. Carterville formation. Light to dark, and shaly and oölitic limestones with some massive soft to hard sandstones. Thickness 0 to 50 ft.	
		Unconformity.	
		2. Boone formation.	1. Upper limestone containing Carthage quarry beds. 100 ft.
			2. Short Creek oölite member. Massive homogeneous bed of oölitic limestone. 2 to 8 ft.
			3. Middle limestone containing Joplin limekiln quarry beds. 100 ft.
			4. Grand Falls chert. 50 to 60 ft.
			5. Lower limestone. 25 to 150 ft.

Faulting.—A fault known as the Duenweg fault cuts across the property of the M. P. B. Mining Company, near Duenweg, which has a maximum throw of nearly 35 feet. Also another fault known as the Portland fault occurs on the land of the Portland Mining Company, just north of Webb City, which shows a displacement of 25 feet. Besides the larger faults, there are scattered over the district many small faults of a few feet displacement. Some of these occur at the surface, but most of them are only seen in the mines. They are associated with more or less fracturing and brecciation. These faults when seen in cross section or for short horizontal distances are not distinguishable, in general, from the dislocations referred to as "solution faults" due to the settling of large blocks owing to underground solution. Solution faults may be associated with fracturing, slickensiding, brecciation or any other ordinary accompaniment of faulting. They differ from the ordinary technical faults in the restriction of the stresses to the settling block concerned and in their vertical limitation to the zone of underground solution.

Brecciation.—The breccias of the district may be divided into three classes—Basal breccias, sheet breccias and zonal breccias.

1. *Basal Breccias.* — These, the familiar "mixed," "confused" or "broken" ground constitute by far the largest proportion of the breccias. They correspond to basal conglomerates except that the fragmentary material has not been rounded or water-worn except to a slight degree. They were formed by shaly or arenacious cementation of angular to subangular blocks and fragments of chert and other rocks residually concentrated upon the slopes and bottoms of the valleys resulting from the solution of the Boone limestone in the formation of Karst topography during the elevation preceding the deposition of the Cherokee formation. Further solution of the underlying limestones caused various readjustments and subsidences of the breccias, resulting in the breaking up of the shale cement and the mingling of shattered blocks of sandstone and limestone with the chert blocks of the breccias. The residual material is usually very much weathered, the chert is "dead" or altered to "cotton rock."

2. *Sheet Breccias.*—These occur principally in the Grand Falls chert and especially at the sheet ground horizon. They have been noted in many of the mines. The heavy ledges of "live," splintery chert have been thoroughly and finely crushed in place and recemented by darker bluish chert, the bedding remaining practically undisturbed.

3. *Zonal Breccias.*—Both sheet and zonal brecciation are associated variously with minor faulting, solution readjustment, warping and horizontal thrust. Both sheet and zonal breccias have often been produced in the following way. Where post-Boone erosion cut valleys down to the Grand Falls chert and these were later filled with shale and the entire formation subjected to lateral thrust, the limestone above the chert moved laterally, compressing the shale in the valley and at the same time produced a belt of sheet breccia at the contact between the limestone and the Grand Falls chert. This is clearly shown in Fig. 11, *A* and *B*. This explains why the Grand Falls chert constitutes the bed rock in so many regions of "broken ground." Furthermore, the beds of chert immediately

below the shale-filled valleys moved upward in obedience to lateral thrust producing zonal breccias. The sheet brecciation in the Grand Falls chert took place presumably wherever there was warping, but the fracture and breccia

A

B

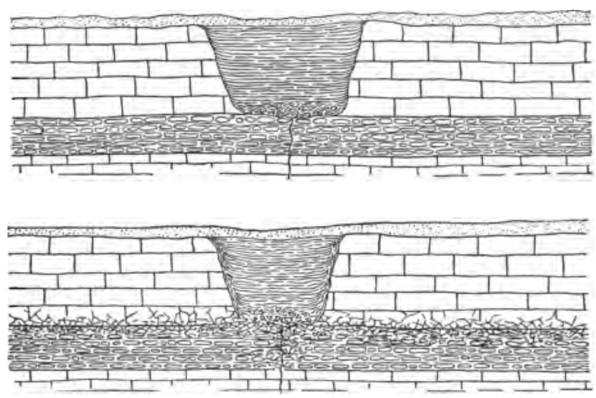

FIG. 11. A. Depression in the limestone extending down to the Grand Falls chert member, filled with Cherokee shale. B. Same after compression. (From U. S. Geological Survey, Folio No. 148, p. 9, Fig. 4.)

The shale has been horizontally shortened, and crumpled and crushed at its contact with the limestone, the wall rock has been brecciated along the chert-limestone contact and in a vertical zone below the shale pocket.

zones are largely limited to the areas of underground solution which, being weakened by jointing and underground drainage, more readily yielded to the stresses of deformation.

Minerals of the Ore Deposits.—The valuable minerals of the Joplin District from an economic standpoint are the lead and zinc minerals. The lead-ore minerals comprise galena in the belt of cementation below ground water level, and a limited amount of cerussite in the belt of weathering. The zinc ores consist chiefly of sphalerite, in the belt of cementation, with a minor proportion of smithsonite and calamine above ground water level. Some of the less important minerals are marcasite, pyrite, chalcopyrite, calcite, dolomite, quartz, greenockite, limonite, gypsum, wurzite, millerite, barite, pyromorphite, anglesite, hydrozincite and goslarite.

Forms of Ore Bodies.—The ore deposits fall into two groups: (1) Runs and their modifications, (2) blanket veins or, as they are generally known, sheet ground deposits.

1. *Runs* are irregular but usually elongated, in places tabular and inclined, bodies of ore, uniformly associated with disturbed strata which have been subjected to brecciation, slickensiding, and moderate displacement as the result of minor faulting or dislocation, due to underground solution. Due to complex causes, the runs often become very complex. The greatest dimension of the runs is horizontal, although the linear extent does not usually exceed a few hundred feet. The Arkansas run at Belleville, with a length of over a quarter of a mile, is exceptionally long. The runs have a maximum width of 300 feet, but, as a rule, are between 10 and 50 feet. The average vertical extent is about the same, but in some cases reaches 150 feet. Many of the runs about Joplin are formed by ore-bearing breccias and massive secondary dolomite coming into juxtaposition along a highly inclined contact plane, the dislocation being due to underground solution. Circular, subcircular and roughly elliptical closed runs, commonly known as "circles" constitute one of the most distinctive and constantly recurring types of ore-bodies in the district. They have been noted in all the more important mining camps, Neck, Oronogo, Webb City, Joplin and Galena. They are especially numerous on the Missouri Lead and Zinc Company's land. The circles vary greatly in size from 110 feet in diameter to 800 feet. The oldest and best known circle in the district is the one at Oronogo. The ore-body usually has the form of a cylinder, dome or truncated cone and a horizontal section has the shape of a circular or elliptical ring. Such deposits are probably due to underground solution, a mass of limestone or chert sinking into a circular cave and producing a circular zone of brecciation on the outside which later becomes cemented partly by ore.

2. *Sheet Ground or Blanket Veins.*—These are nearly horizontal, tabular ore-bodies, many of them of great lateral extent, developed parallel to the bedding planes of the rock. They are, to a certain degree, limited to valleys and to areas of brecciation and solution. The ores of sheet ground are galena and sphalerite occurring in

part along the bedding planes of cherts, and in part in breccias resulting from slight folding or faulting of the bedded rocks or from slight differential movement between the beds. Typical sheet ground seems to be developed invariably in the Grand Falls chert. By far the most extensive development of sheet ground seems to be between Webb City and Prosperity and to the northwest and southeast of that area. The best sheet ground between Webb City and Prosperity averages about 6 per cent. ore. Per cents. as low as 2 or 2.5 are worked, but with very little profit.

Vertical Distribution of the Ores.—The most noticeable feature of vertical distribution of the ores is the abundance of galena in the upper parts of the deposits with little or none in the lower levels. On the other hand, sphalerite is most abundant in the middle and lower parts of many of the deposits. This vertical relation of galena and sphalerite, though by no means universal, is common throughout the district.

Vertical Extent of the Ores.—Up to the present time mining has been confined to those parts of the Boone formation which lie above the base of the Grand Falls chert. Within this interval there seems to be no general increase or decrease in value with depth and no well-defined ore horizon except that of the sheet ground, the deepest of the deposits mined. In some instances, as at the Oronogo circle, the ore is, in places, practically continuous from the sheet ground horizon to the surface. In other instances there may be in the same interval several ore horizons separated by barren ground.

Genesis of the Ores.—The immediate source of the ores is believed to be the various limestone formations of the Ozark region beneath the Pennsylvanian rocks.

Underground Circulation.—The Joplin district lies on the northwestern slope of the Ozark uplift which is an asymmetric dome of crystalline rocks surrounded by Paleozoic sediments. Beneath the thick body of Pennsylvanian shale and sandstone which fringes the uplift are the Mississippian rocks several hundred feet in thickness. To the latter series belongs the Boone formation, characteristically the ore-bearing formation of the Joplin District. The Mississippian limestones are underlain by thin, nonpersistent shales of Hannibal and Chattanooga age; and

these in turn are succeeded below by a series of Cambro-Ordovician and Cambrian rocks. This series has a thickness in the Joplin District of 1,300 feet and rests upon pre-Cambrian crystalline rocks. The catchment area of the artesian circulation extends toward the south and east at least as far as the crest of the uplift and includes extensive exposures of both Mississippian and Cambro-Ordovician rocks. Meteoric waters falling over this area sink downward and flow in the direction of the dip toward the northwest. As the underground water rises, due to hydrostatic pressure, fractures encountered in the course of its circulation serve as channels for communication not only between different beds, but where the fractures are of sufficient extent between the formations as well. The wide-spread dislocation and brecciations of the Joplin District have allowed a commingling of the waters not only from different parts of the Boone formation, but probably also from the Cambro-Ordovician rocks. Says W. S. Tangier Smith, in Folio 148, of the U. S. G. S.: "The common association of lead and zinc ores with limestone; the known occurrence of these metals in sea-water; their probable precipitation, in minute quantities, in limestone laid down in these waters; the actual wide-spread occurrence of lead and zinc in very small amount in the limestones of the Mississippi Valley, both Carboniferous and Cambro-Ordovician; together with the fact, already mentioned, that the general course of circulation reaching the Joplin District is through such lead- and zinc-bearing calcareous formations, render it reasonably certain that these formations are the source of the ores."

Secondary Enrichment.—Secondary enrichment of the lead and zinc ores includes: (1) Oxide enrichment, (2) sulphide enrichment.

1. *Oxide Enrichment* includes the accumulation of the products of oxidation in the form of carbonates or silicates in the belt of weathering.

2. *Sulphide Enrichment* includes the oxidation of the ores within the belt of weathering, their removal in solution by descending waters, and the reprecipitation of more or less of their dissolved ore as sulphides, below groundwater level at a horizon where ore already exists, thus enriching the deposit by adding to the amount of the ore.

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

References for Joplin District.

1. Folio No. 148, U. S. G. S., by W. S. T. Smith and C. E. Siebenthal.
2. Bull. 213, U. S. G. S., p. 197, by W. S. Tangier Smith.
3. *Econ. Geol.*, 1, pp. 119–129, Nov.–Dec., 1905, by C. E. Siebenthal.
4. A. I. M. E., Vol. 21, pp. 3–25, by C. Henrich.
5. A. I. M. E., Vol. 31, pp. 379–404, by Eric Hedburg.
6. 22nd Ann. Rept., U. S. G. S., Pt. 2, pp. 30–226.

Zinc Deposit of Franklin Furnace Quadrangle.—The following summary is taken chiefly from the No. 161, U. S. G. S., by A. C. Spencer, R. D. Salisbury and H. B. Kümmel. This quadrangle is approximately 17 miles in length and 13 miles in width, and lies in northwestern New Jersey, chiefly in Sussex County. The quadrangle is divisible, topographically, into three parts —the Kittatinny Mountain region, in the northwest corner; the Kittatinny Valley, a depression 7 to 10 miles wide and from 600 to 800 feet deep, lying immediately to the southeast; and the Highlands, occupying somewhat less than one half the area, southeast of the valley. These various features have a northeast-southwest trend, indicating the structure of the underlying formations. Says A. C. Spencer, in Folio No. 161: "The rocks of the Franklin Furnace Quadrangle comprises a series of crystalline gneisses and limestones older than the Cambrian, stratified formations ranging in age from Cambrian to Devonian, and intrusive rocks later than Ordovician. The district exhibits the northeast-southwest trend of topography and areal geology which characterize the Appalachian Province southward from Hudson River. Red sandstones and shales occur in the northwest corner of the quadrangle, overlying the more massive quartzites and conglomerates of Kittatinny Mountain. These formations which are of Silurian age dip to the northwest. Below them are Ordovician shales which cover the greater part of Kittatinny Valley. Numerous dikes and a few stocks of nephelite-syenite cut the shale in the western part of Wantage Township. The southeast side of the main Kittatinny Valley is occupied chiefly by a belt of Cambro-Ordovician limestone, separated from the old crystalline rocks by a thin basal sandstone of Cambrian age. Southeast of this belt, and well within the general area of the older rocks, are several

outlying strips of limestone. . . . Each of these strips is limited on the southeast by the basal sandstone and on the west by a fault of considerable displacement. Between the Paleozoic stratified formations and the rocks of the ancient crystalline complex there is a great unconformity, the older rocks having been deeply eroded previous to the deposition of the Cambrian sandstone. On both sides of the New York-New Jersey boundary the general area of the Highlands is divided longitudinally by a belt of Silurian and Devonian formations. This belt traverses the southeast corner of the Franklin Furnace Quadrangle, where Green Pond and Bowling Green Mountains have been preserved by the presence of resistant Silurian sandstones and conglomerates. Aside from the inlying strips of Cambro-Ordovician limestone and the belt of Silurian-Devonian rocks which have been mentioned, the rocks of the Highlands are gneisses and crystalline white limestones, with minor masses of coarse-grained granite or pegmatite and a few diabasic dikes. The highly metamorphosed limestones occur in a few minor areas west of Wallkill River, and in a zone extending from the vicinity of Ogdensburg, northeastward, well into Orange Co., N. Y.'' In the same folio, H. B. Kümmel says, concerning the structure of the Paleozoic rocks: ''The Paleozoic rocks of this quadrangle have the northeast-southwest structure lines characteristic of all parts of the Appalachian Province. This feature is due primarily to a system of folds whose axes trend northeast and southwest and to a series of faults which have the same general direction. Although the structure is simple in its major features, in detail it is much more complex. Minor folds, some of them closely compressed and in places overturned, occur within the larger folds and complicate the structure. These smaller folds are more common in the slate and shale of the Martinsburg, than in the massive Kittatinny limestone, and occur more abundantly in the lower layers of the slate where the sediments are finer than in the upper beds, where thick layers of sandstone are numerous. In other words, the thinner-bedded, less resistant sediments have yielded by crumpling, whereas the more massive layers have accommodated themselves to the pressure by forming folds of much greater radius. The folds are rarely symmetrical; on the

contrary one limb is usually much steeper than the other. . . . In addition to the close folding in the northeast-southwest direction, the strata are affected by a series of cross folds of great length and low amplitude which manifest themselves in a slight pitch of the axes of the northeast-southwest folds. Most of the larger folds are cut off by faults along their flanks, in places parallel and in places oblique to their axes. Almost without exception the uplift has been on the northwest side, the beds on the southeast having been relatively depressed. The amount of dislocation ranges from a few feet to probably several hundred or even a thousand feet or more. . . . The folding is probably to be referred to the general movement which affected the Appalachian region at the close of the Paleozoic era. . . . Some of the faulting probably accompanied folding and some of it undoubtedly occurred later."

Ore Deposits.—In the Franklin Furnace Quadrangle mining is at present confined to zinc ores occurring in the property of the New Jersey Zinc Company at Franklin Furnace. Pyrite deposits were worked by the manufacturers of copperas during the War of 1812. Iron ores were worked at intervals from the Revolutionary period down to very recent years, and several early forges were operated at Hamburg, and Franklin Furnace and along Pequanac river near Stockholm. During the prosperous years of the iron trade between 1890 and 1893 a furnace owned by the Franklin Iron Company was in blast at Franklin Furnace; but this industry was never entirely supported by the products of local mines. No metals other than zinc, iron and manganese have ever been mined on a commercial scale, though somewhat extensive explorations were made at one time in the attempt to develop certain occurrences of silver-bearing galena near the Andover Iron mines and at a locality three miles east of Newton. Graphite occurs locally in the dark gneisses, at a few places in the masses of pegmatite, and very generally throughout the Franklin limestone, but no serious attempt at mining this mineral is known to have been made.

Zinc Mines.—Says A. C. Spencer regarding the zinc deposits: "Two large bodies of zinc-bearing ore, different in character from any other known ore deposit, occur at

Mine Hill, near Franklin Furnace, and at Sterling Hill, near Ogdensburg. The complex ore of Mine Hill and Sterling Hill are composed of varying proportions of the valuable minerals, franklinite, willemite, and zincite, usually mixed with calcite and in places further contaminated by a variety of silicate minerals, including garnet, tephroite and rhodonite. In parts of the vein franklinite is the only metallic mineral; elsewhere it is accompanied by both willemite and zincite, or by one of these alone; and in still other places there are layers composed mainly of rounded grains or bunches of zincite set in a matrix of coarsely crystalline calcite. In the great bulk of the ores as mined the minerals occur in the form of dull rounded grains which appear to be corroded crystals. . . . The texture of the ore is highly granular and in much of it foliation is strongly marked. . . . At Mine Hill the ore has been estimated to contain from 19 to 22.5 per cent. of iron, 6 to 12 per cent. of manganese, and 23 to 29 per cent. of zinc. . . . Figures giving the metallic content of the Sterling Hill ore have not been published, but it is known to average considerably lower in zinc than the ore from Mine Hill. . . . As now operated, the Wetherell magnetic concentrators yield from crushed ore three products, known as franklinite, half-and-half and willemite. The first product, composed mainly of franklinite, is used for the preparation of zinc white, the residuum from this process going to the blast furnace to make spiegeleisen. The half-and-half contains franklinite, rhodonite, garnet, and other silicates, with attached particles of the richer zinc minerals. This product carries somewhat more zinc than the franklinite. It is used for zinc white but its residuum is too high in silica for the spiegel furnaces. The willemite product consists of willemite and zincite with calcite and silicate minerals as impurities. The calcite is removed by means of jigs and concentrating tables, leaving material suitable for high-grade spelter, free from lead and cadmium."

The Mine Hill Deposit.—The ore bodies both at Mine Hill and Sterling Hill are bedded deposits formed in the limestone, which has been rather closely folded. Regarding the Mine Hill ore-body A. C. Spencer says: "The ore-mass at Mine Hill is a layer varying in thickness from 12 feet to 100 feet or more, bent upon itself to form a long

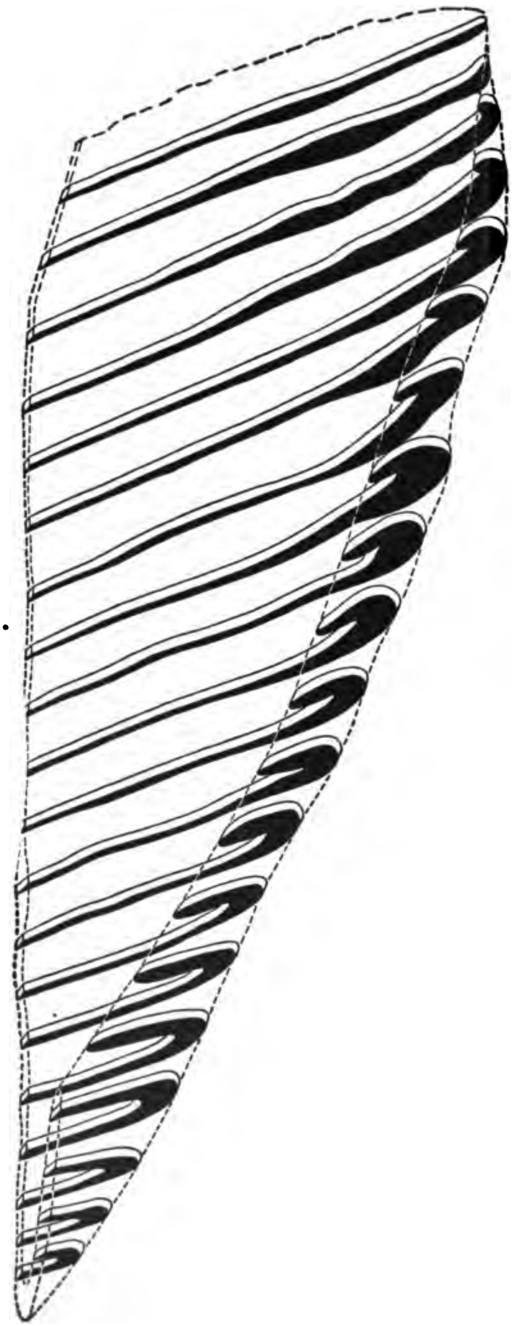

FIG. 12. Stereogram of Mine Hill ore body. (From U. S. Geological Survey, Folio No. 161, p. 24, Fig. 11.)

trough with sides of unequal height. The character of the ore-body is well shown in the accompanying Fig. 12. The trough lies with its keel pitching in a northerly direction at an average rate of 36 feet per 100 for a horizontal distance of about 2,800 feet from the elbow of the hook-shaped outcrop at the south end of Mine Hill. Still farther toward the north it rises at the rate of 16 feet per 100 for 600 feet, to the north edge of the deposit. The west flank rises from the keel at an average angle of about 55 degrees and comes to the surface along the northwest brow of the hill. Its outcrop is about 2,600 feet in length, but toward the north its full extent is not seen because the top of the formation is capped by Palezoic formations. The greatest dip length of the west vein, measured from the surface to the bottom of the trough, about 1,350 feet, is on a section near the most northerly outcrop. On either side of this the height of the vein is less. Near the north edge of the deposit its full height, though not yet determined, is probably not more than 1,000 feet. Toward the south the height decreases through the gradual rising of the keel. The east flank has not been fully developed in the underground workings, but enough is known to show that its attitude is somewhat variable. In the lower part of the mine it apparently stands nearly vertical. Farther south it dips strongly to the east and locally lies nearly parallel with the west leg; and still farther south, as its outcrop is approached, it either stands nearly vertical or dips steeply toward the east. This side of the trough appears at the surface for a distance of about 600 feet northward from the elbow where it is joined by the outcrop of the west leg.''

The Sterling Hill Deposit.—Regarding the Sterling Hill deposit Mr. Spencer says: ''The Sterling Hill deposit, like that of the Mine Hill, is a layer in the form of a trough. The layer ranges in thickness from 10 to 30 feet, and in places it is composed of two parts, one rich in zincite, and the other composed largely of franklinite. The sides of the trough, which are of unequal height, both strike in a northeasterly direction, the lower west flank outcropping for about 600 feet and the higher east flank for about 1,500 feet from the sharp elbow at the southwest where they meet. Both veins dip toward the south-

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

east and the keel of the trough plunges in an easterly direction. Near the surface the west vein dips about 45 degrees. Underground in different parts of the mine the east vein, which is the one principally developed, shows dips averaging from 45 to 60 degrees, and from the mine maps it is seen that on each level the inclination of the ore layer becomes gradually steeper as the keel is approached." Owing to the peculiar nature of these deposits, both in structure and composition, and the few deposits of like character in existence, the genesis of the ores seems to be somewhat in question.

References for the Franklin Furnace District.

1. Folio No. 161, U. S. G. S., by A. C. Spencer, R. D. Salisbury and H. B. Kümmel.
2. Bull. 213, U. S. G. S., p. 214, by J. E. Wolff.
3. "Geology of New Jersey," 1868, p. 669, by G. H. Cook.
4. *N. Y. Acad. Sci.*, Vol. 13, pp. 76–98.

CHAPTER VII.

SILVER-LEAD ORE DEPOSITS.

The Leadville District, Colorado.—The following is a brief extract from monograph XII, U. S. G. S., by S. F. Emmons. This district is situated in Lake County, Colorado. The first discovery of gold was made by a party of prospectors in 1860 in what is known as California Gulch. It is estimated that fully 10,000 persons came into the gulch during the first summer and took away $2,000,000 worth of gold. This however may be considerably exaggerated. The first gold vein was discovered in 1868 and the real value of the famous carbonate deposits was not recognized until 1874. The first "carbonate-in-place" was found at the mouth of the present rock tunnel on Dome Hill. The famous orebodies on Frier Hill were discovered in 1877. As to the magnitude of its product the Leadville District in 1886 had been only surpassed in the United States by the famous Comstock Lode in the Washoe District in Nevada. The rapidity of its development was even more remarkable than that of the latter. The metallic production of Lake Company, Colorado, in 1907 comprising in the main the Leadville district was as follows: 57,504.38 fine ounces gold; 4,154,913 fine ounces silver; 2,679,510 pounds copper; 32,519,796 pounds lead; 37,412,374 pounds zinc. The ores of Leadville comprise oxidized iron ores for flux, oxidized lead ores, lead and zinc sulphides of shipping grade, dry gold ores, dry silver ores of shipping grade and dry sulphides. During the last few years the value of the ore has decreased while the tonnage has been greatly increased. The succession of formations of the Misquito Range, which comprises not only the Leadville District, but also an additional area to the north and east is as follows:

Tertiary	1. Rhyolite. Consisting mainly of sanadine with satiny luster, and smoky quartz. 2. Andesite. Often normal hornblende andesite.

Late Mesozoic.

1. Mount Zion Porphyry. Gray, resembling fine-grained granite consisting mainly of quartz, feldspar and mica. Rarely found unaltered. Partly decomposed biotite produces a spotted appearance, becomes whiter and resembles the white porphyry.
2. White or Leadville Porphyry. White or granular, compact, homogeneous-looking rock composed of quartz, feldspar, and muscovite. Among miners known as Block Porphyry on account of its tendency to split up into angular blocks, and "forest rock" from the dendritic markings of manganese oxide on the cleavage surfaces.
3. Lincoln Porphyry. Typically developed around Mt. Lincoln. Contains large crystals of pink orthoclase from one inch upwards in size. Plagioclase in small, white, opaque crystals. Quartz in hexagonal pyramids and mica in six-sided plates.
4. Gray Porphyry. Apparently a decomposed Lincoln or Eagle River porphyry. Has same mineral composition and can be traced as a continuous sheet through transition forms into the latter.
5. Sacramento Porphyry. Dark-gray, granular, rather even-grained rock, in which groundmass is entirely subordinate and contains quartz, two feldspars, biotite and hornblende.
6. Pyritiferous Porphyry. White colors with grayish-green or pinkish tints, comparatively fine-grained and with no traces of large crystals. Contains small grains of white feldspar, quartz, biotite usually altered to chlorite, and pyrite. The pyrite is abundant.
7. Mosquito Porphyry. Light-gray, fine-grained rock exclusively in form of dikes and contains chiefly quartz, two feldspars and biotite.
8. Green Porphyry. Fine-grained, compact, of light green color due to chloritic decomposition of the original constituents. Quartz, two feldspars, biotite and hornblende have been identified.
9. Silverheels Porphyry. Extremely fine-grained, greenish-gray rock, characterized by fine needles of apparently decomposed hornblende.
10. Diorite. Comprising hornblende diorite, quartz-mica diorite, and augitic diorite.
11. Porphyrite. Characterized by a great predominance of basic silicates, rareness of quartz, and younger field habit as shown by the conchoidal fracture and fresher appearance.

Carboniferous.	1. Upper Coal Measures.		Blue and drab limestones and dolomites with red sandstones and shales. Mud shales at the top. 1,000 to 1,500 ft.
	2. Weber Grits..	2,500 feet.	Coarse white sandstones, passing into conglomerates, and siliceous and highly micaceous shales, occasional beds of black argillite and blue dolomitic limestone.
	3. Weber Shales.		Calcareous and carbonaceous shales with quartzite.
	4. Blue Limestone.		Compact, heavy-bedded, dark-blue dolomitic limestone. Siliceous concretions at top in the form of black chert. 200 ft.
Silurian	1. Parting Quartzite.		White quartzite. 30 ft.
	2. White Limestone.		Light-gray siliceous, dolomitic limestone, with white chert concretions. 160 ft.
Cambrian	1. Lower Quartzite.		White quartzite passing into calcareous and argillaceous shales above. 150 to 200 ft.
Archean			Granite, gneiss, schists, amphibole, etc.

Says S. F. Emmons in Monograph 12 of the U. S. G. S.: "The simplest expression of the geological structure of the Rocky Mountains in Colorado is that of two approximately parallel uplifts or series of ridges of Archean rocks upon whose flanks rest at varying angles a conformable series of sedimentary formations extending in age from the earliest Cambrian to the latest Cretaceous epochs, the latter being locally overlaid by unconformable Tertiary beds. The eastern uplift is known as the Colorado or Front Range, the western as the Park Range." In the latitude of Leadville the Park Range consists of two distinct ranges, the Misquito Range and the Sawatch Range. Between the two ranges lies the valley of the Upper Arkansas River. On the upper edge of one of the terraces on the east side of the valley is situated the City of Leadville, up from which the land gradually rises toward the summit of Misquito Range on the east.

Geological History.—Although more briefly stated, the following, I take it, represents Mr. Emmons views regarding

geological history of the district. During the erosion of the Archean Island which occupied the present position of the Sawatch Range there was deposited during paleozoic and Mesozoic time a conformable and almost continuous series of coarse sandstones and conglomerates, alternating with dolomitic limestones and calcareous and argillaceous shales as the geological succession shows. During the long period of conformable deposition there was an accumulation in the area of 10,000 to 12,000 feet of sedimentary beds.

Toward the latter part of this period there was an exhibition of eruptive activity, during which enormous masses of molten rock were intruded through the underlying Archean floor into the overlying sedimentary deposits, crossing the beds, then spreading out in immense sheets along the bedding planes. The intrusive force is shown by the fact that these sheets of molten rock were forced continuously for distances of many miles between the beds. That this eruptive activity preceded the movement at the close of the Cretaceous which caused the uplift of the Misquito Range as well as other Rocky Mountain ranges is proved by the fact that these interbedded sheets of eruptive rocks, porphyries and porphyrites, are found practically conformable with their bounding strata, and, like them, folded into sharp folds and cut off by faults. Sometimes fifteen or twenty separate intrusive beds from 50 to 200 feet in thickness are found in one single vertical section. At some time during the long period between the final deposition of the latest Cretaceous sediments and the deposition of the Tertiary strata, the pent-up energy of the force of contraction of the earth's crust, which had accumulated during ages of tranquillity found expression in dynamic movement. This movement in its simplest form may be conceived as a pushing together from the east and from the west of the more recent stratified rock against the relatively rigid mass of the already existing Archean land masses and a consequent folding or crumpling of the beds in the vicinity of the shore lines where conditions were most favorable for crumpling movement. The uplift of the Misquito Range, of which the Leadville District forms a part of the western slope, was not the simple pushing up of the beds into a simple monoclinal fold, but a somewhat irregular

plication of them into anticlinal and synclinal folds, and their fracturing by faults, which have the same general direction as the axes of the folds without coinciding exactly with them and which often pass into folds at their extremities. The anticlinal folds have as a rule a very steep inclination, sometimes nearly vertical, on the west side of the axis and a more gentle slope to the east. It is along this steeper slope that the fracturing has generally taken place and the fault may thus follow the axis of a syncline or of an anticline according as it runs to one side or the other of this steep slope. Other forces acting from north to south produced folds whose axes run east and west. These are well known by the wavy character of the outcrops where the sediments lap up over the crystalline schists.

Displacement.—The movement of displacement of the faults has been with few exceptions an upthrow to the east. The maximum movement of any one fault is that of the Misquito fault at the northern edge of the map, which is about 5,000 feet.

Time of Mineral Deposition.—It was during the period which intervened between the intrusion of the eruptive rocks and the dynamic movements which uplifted the Misquito Range that the original deposition of metallic minerals in the Leadville region took place. Their manner of occurrence and the probability that they were derived, in great part at least, from the eruptive rocks themselves prove that they must be of later origin than the latter, while the fact that they have been folded and faulted together with the inclosing rocks, both eruptive and sedimentary, shows that they must have been formed prior to the dynamic movements, and that they are therefore older than the Misquito Range itself.

Manner of Occurrence of Ores.—From Mr. Emmons's own statements we learn that by far the most important of the ores of Leadville and vicinity, both in quantity and quality, occur in the blue limestone and at or near its contact with the overlying sheet of porphyry which is generally the white or Leadville porphyry. They constitute a sort of contact sheet, whose upper surface, being formed by the base of the porphyry sheet, is comparatively regular and well defined, while the lower surface is ill defined and irregular, there being a gradual transition

from ore into unaltered limestone, the ore extending to varying depths from the surface and even occupying at times the entire thickness of the blue limestone formation. The above is the typical form of the Leadville deposits. There are, however, variations from this form and also in the character of the inclosing rock which do not involve any difference in origin. For example, the ore sometimes occurs in irregularly-shaped bodies or in transverse sheets not always directly connected with the upper or contact surface of the ore-bearing bed or rock; it also occurs at or near the contact of sheets of gray or other porphyries with the blue limestone, and less frequently in sedimentary beds, both calcareous and siliceous, and in porphyry bodies, sometimes on or near contact surfaces and sometimes along joint or fault planes. In general it may be said that the main mass of argentiferous lead ores has been found in calcareo-magnesian beds, while the ores containing gold and copper are more frequently found in siliceous beds, in porphyries, or in crystalline rocks.

Composition of Deposits.—By far the most important ore from an economic point of view, is argentiferous galena, with its secondary products, carbonate of lead and chloride of silver. Lead also occurs as the sulphate, anglesite, as pyromorphite, as the oxide in the form of litharge and more rarely in the form of minium. Silver frequently ocurs as chloro-bromide embolite, less frequently in the native state. Basic ferric sulphate often occurs as an alteration product of mixed pyrite and galena. Gold occurs in the native state, usually in extremely small flakes or leaflets. Some of the accessory minerals are sulphide and hydrous silicate of zinc, sulphide of arsenic, sulphide of antimony, molybdate of lead or wulfenite, carbonate or silicate of copper, sulphide and sulpho-carbonate of bismuth, vanadate of lead and zinc, and the sulphide and the hydrous and anhydrous oxides of iron. Some of the gangue minerals are silica, hydrous silicates of aluminium, barite, siderite, pyrite and gypsum.

Origin of the Metals.—That the immediate source of the metals of the Leadville District was due to downward moving waters rather than to waters coming up from great depths is indicated by the following field observations, which are stated by Mr. Emmons as follows:

"First. The geological study of the district has shown

that the metals must have been formed beneath a thickness of at least ten thousand feet of superincumbent rocks and an unknown amount of sea-water. If they had been deposited from hot ascending solutions, as the result of relief of pressure, it would naturally be expected that the bulk of the deposit would have been found in the upper part of this mass of rocks, where the pressure was least instead of at its base.

"Secondly. Since at the time of deposit the sedimentary beds in which the ores occur were horizontal and relatively undisturbed, if the deposits had been made from ascending currents it would naturally be expected that the process of deposition should have acted from the lower surface of the beds upward, instead of from the upper surface downwards, as is shown in the case of the blue limestone, which carries the bulk of the ores.

"Thirdly. As far as present investigations have extended there is a noticeable absence, in the region of greatest ore development, of channels extending downwards through which the ascending solutions might have come. The vast majority of eruptive bodies are in the form of nearly horizontal sheets, parallel with the stratification. The few approximately vertical bodies that have come under observation afford no evidence that their walls form part of a channel through which the ore currents came up from below."

Regarding the circulation of water through massive or eruptive rocks, Emmons says: "It is well known that percolating waters circulate freely in every direction through massive or eruptive rocks, owing to the effect which cooling and weathering have of splitting them into irregular blocks, while in sedimentary rocks, however permeable, the bedding planes are naturally the easiest for them to follow. If, then, at the time of deposition the prevailing direction of the ore currents had been downward, it is easy to conceive that they would have descended freely through the overlying porphyry masses and would have been diverted temporarily from a vertical to a horizontal course along the stratification plane of the first sedimentary bed they reached, and that, when this was a comparatively soluble rock like the dolomitic limestone of Leadville they would eat their way gradually into it, either from this surface or from cracks through which they were

here and there able to penetrate its mass. A downward current, seems, therefore, to best suit the facts thus far observed in the Leadville deposits."

It cannot be supposed that waters would travel for a great distance through rocks of varying composition without suffering considerable change in the material they held in solution, therefore it was perfectly natural for those studying the origin of the metals, to consider the chemical nature of the fresh unaltered portions of the rocks in the vicinity of these deposits, and from the conclusion heretofore mentioned, especially those overlying them. Such constituents of the ores as silica, iron and manganese are so universally disseminated throughout the rocks that a search was considered unnecessary. Strontium replaces barium to a certain extent in the Leadville deposits. Out of eleven specimens of eruptive rocks analyzed, five contained baryta, five strontia, and in three neither was detected. The following table shows the results of lead determinations in specimens of eruptive rocks. Of the specimens taken, all except granite and porphyrite belong to a higher geological horizon than the blue limestone.

Rock.	Number of Specimens Tested for PbO.	Number Containing PbO.	Number in which no PbO was Found.
White porphyry	2	2	0
Gray porphyry	1	1	0
Lincoln porphyry	3	2	1
Pyritiferous porphyry	8	8	0
Porphyrite	2	1	1
Granite	2	1	1
Total	18	15	3

Although the above facts are not sufficiently conclusive to furnish absolute proof that the metallic contents of the deposits were entirely derived from the eruptive rocks, they certainly show the possibility that this source furnished a part, at least, of the vein materials.

The following table shows the results of gold and silver determination of specimens of eruptive rocks:

Rocks.	Number of Specimens Tested.	Number Containing Silver.	Number Containing Gold.	Number in which Neither was Found.
White porphyry	11	3	(?)	8
Gray porphyry	3	3	1	0
Lincoln porphyry	6	5	0	1
Pyritiferous porphyry	10	9	3	1
Sacramento porphyry	1	1	0	0
Green porphyry	1	1	0	0
Diorite (augite)	1	1	0	0
Porphyrite	6	6	0	0
Andesite	1	1	0	0
Rhyolite	1	1	0	0
Trachyte	1	1	0	0
Granite	2	0	0	2
Total	44	32	4	12

References for the Leadville District.

1. Monograph XII, U. S. G. S., by S. F. Emmons.
2. Bull. 320, U. S. G. S., by S. F. Emmons and J. D. Irving.
3. *Eng. Mg. Jour.*, May, 1886, p. 33, by C. Henrich.
4. Int. Mg. Cong., 4th Session, Proc., pp. 175–179, by C. J. Moore.
5. *Eng. Mg. Jour.*, Vol. 41, p. 36, by C. M. Rolker.

Cœur d'Alene District.—The following notes are taken principally from Bulletin 260, U. S. G. S., by F. L. Ransome. This district is located in Shoshone County, Idaho. It lies almost entirely on the western slope of the Cœur d'Alene Mountains, a broad and rather complex member of the main Rocky Mountain chain. The elevations in the district range from 6,826 feet on the summit of Mount Stevens to 2,250 feet on the south fork of the Cœur d'Alene River.

The first quartz claim was located in 1878. In 1882 placer gold was found on Prichard Creek and the center of population soon shifted to the new town of Murray. Soon the rich lead-silver veins of the south fork of Cœur d'Alene River began to attract attention. The great wealth of the district was fully realized but lack of transportation facilities limited the amount of production until the tracks of the Northern Pacific and Oregon Railway and Navigation Company were completed into the district in 1890. In spite of lack of transportation facilities, labor troubles, etc., the district has been, for several years, the leading lead-producing district in the United States. The gold is derived almost entirely from the placers and gold quartz veins near Murray. The lead-silver ores produce

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

almost no gold. The silver is all obtained by smelting the lead-silver ores.

The production of Shoshone County, which is virtually the production of the Cœur d'Alene District, in 1907, was as follows: Gold, 395,204 fine ounces; silver, 7,266,862 fine ounces; copper, 10,890,731 pounds (chiefly, but not entirely, from Shoshone County); lead, 233,832,854 pounds (chiefly from Shoshone County); zinc, 6,985,732 pounds (chiefly from Shoshone County).

No sediments younger than Algonkian occur in the Cœur d'Alene District with the exception of fluviatile deposits, some of which may be of Tertiary age. The generalized section of rocks in the district is as follows:

Algonkian ...

1. Striped Peak Formation. Sandstones, siliceous, generally flaggy to shaly; color mostly green and purple; characterized by shallow-water features, as ripple marks, sun cracks, etc.
2. Wallace Formation. Thin-bedded sandy shales, underlain by rapidly alternating thin beds of argillite, calcareous sandstone, impure limestone, and indurated calcareous shale; these underlain in turn by green siliceous argillites. Shallow-water features throughout. Slaty cleavage common.
3. St. Regis Formation. Sandstones, generally flaggy or shaly; usually fine-grained and much indurated; colors mostly green and purple; characterized by shallow-water features.
4. Revette Quartzite. White quartzites, generally rather thick-bedded; interstratified with subordinate quantities of micaceous sandstone.
5. Burke Formation. Gray, flaggy, fine-grained sandstones, and shales, with interbedded purple quartzitic sandstone (the proportion varies widely in different parts of the district) and white quartzite. The formation characterized throughout by shallow-water features.
6. Prichard Slate. Mostly blue-black, blue-gray to light-gray slates, generally distinctly banded. Considerable interbedded gray sandstone. Upper portion characterized by rapid alternations of argillaceous and arenaceous layers, and by shallow-water features. Base not exposed:

Post Algonkian.—Syenite and monzonite. In the larger areas northeast of Wallace is a coarse-grained syenite with a tendency toward porphyritic development of the

dominant alkali feldspar. Other essential constituents are plagioclase, amphibole and pyroxene. In the largest mass near Gem are found monzonite facies.

The large syenitic intrusions are surrounded by well-marked zones of contact metamorphism. The quartzites are altered to hornfels. The impure quartzites and argillites are recrystallized as aggregates of andalusite, garnet, sillimanite, biotite, muscovite, quartz and feldspar. The dike rocks of the district which seem to have no communication direct with the syenitic intrusions have no great structural or economic importance.

Structural Features of the District.—The sedimentary rocks of the district have been complexly folded, the folds, in several instances, being overturned so that the older formations overlie the younger. They have also been extensively faulted and so strongly compressed as to develop slaty cleavage in all but the massive quartzites. The strike of the beds is usually northwest, although this is by no means universal. The majority of the faults strike nearly west-northwest. Both normal and reversed faults occur, the dip of the reversed faults being usually steep. Faults are especially abundant in the southern part of the district. They have throws of from 1,000 to at least 4,000 feet and observed lengths up to eighteen miles. The west-northwest faults have approximately the same general strike as the lead-silver lodes and were produced by the same or similar stresses. Certain faults have a nearly north-south trend. They are characteristic of the central part of the district. *E. g.*, Dobson Pass fault which has been traced practically from Wallace to Eagle, dips west at an angle of 35 degrees and is normal. Five miles north of Murray the fault has dropped the Striped Peak formation against the Prichard slate indicating a throw of at least 6,000 feet.

Ore Deposits.—The ore deposits of the district may be divided with reference to metallic contents into three classes: (1) Lead-silver deposits, (2) gold deposits, (3) copper deposits.

1. Lead-silver Deposits.—Most of these deposits are metasomatic fissure veins. They are generally tabular deposits, formed partly by the filling of open spaces, but largely by replacement along zones of fissuring or of combined fissuring and shearing. The general strike of the

lodes is northwest and the dip almost vertical. The mineralized fissures have the characteristics of faults. They differ from the great faults of the region in that the large structurally important faults are not ore-bearing. Frequently the lodes consist of mineralized zones of fissures, the fissuring and cleavage being so closely related that the structure may be termed a shear zone. The principal lead-silver deposits are found in the Burke formation. The most characteristic minerals are galena and siderite. Sometimes the galena directly replaces the sericitic quartzite. Again, as at Wardner, the quartzite is replaced by siderite and that in turn by galena. That galena was formed at more than one period is shown by the fact that masses of coarsely crystalline galena are sometimes traversed by veinlets of a more compact variety of the same mineral. Pyrite and sphalerite are found in all the deposits.

The presence of tetrahedrite always indicates ore rich in silver. The ores found in the oxidized zone are cerussite, cerargyrite, native silver, pyromorphite with some malachite, azurite and considerable limonite.

Quality of Ore.—The average content of the ores in silver is a little over half an ounce to each per cent. of lead per ton. During the fiscal year, 1903–4, the ore of the Bunker Hill and Sullivan mines averaged 8.8 per cent. lead and 3.9 ounces of silver. The Morning mine in 1903 averaged 7.4 per cent. lead and 2.9 ounces of silver. The Helena-Frisco mine, in 1903, averaged 4.5 per cent. lead and 2.7 ounces silver. The latter is unprofitable. The richest ore produced in 1903, on a large scale, was that of the Hercules mine with approximately 50 per cent. of lead and 45 ounces silver per ton. This, however, was picked material as the mine did not, in 1903, concentrate any of its ore.

2. Gold Deposits.—The only gold-bearing veins that are now productive occur near Murray. The best known veins near Murray are the Golden Chest, just north of Littlefield, and the Mother Lode group of veins on Ophir Mountain, situated on the south side of Prichard Creek between Littlefield and Murray. With few exceptions, the veins of the Murray area belong to the class known as bed veins. They usually follow the stratification planes of the Prichard formation. Occasionally they jump from

one vein to another, the two parts of the vein being connected by small stringers across the intervening bed. In the Golden Chest mine there are at least six of these bed veins in a zone 150 feet in width. They strike N. 17 E. and dip westward from 40 to 45 degrees. The veins vary in width from 1 to 10 feet. They are filled with quartz containing free gold, auriferous pyrite, galena, sphalerite and chalcopyrite with occasional bunches of scheelite. The best ore is said to have been worth $70 to $90 per ton. The ore now worked in the 20-stamp mills is of much lower grade, probably running not over $7 per ton. There are other very rich veins, but the veins as a whole are of rather low-grade and have not been stoped more than a few hundred feet from the surface.

Placers.—The placer deposits of Murray constitute what is locally called the Old Wash and are remnants of an earlier channel of Prichard Creek from 250 to 300 feet above the present stream. These gravels have not proved very rich. Most of the placer gold of the Murray region has come from the bottoms of the existing gulches and has been obtained by simple sluicing, booming, drifting and dredging. At present about $6,000 a year is obtained from the gravels of Trail Creek by booming.

3. Copper Deposits.—The only productive copper deposit in the district is that of the Snowstorm mine, in the Revett quartzite, east of Mullan. The deposit consists of an impregnated cupriferous zone, which conforms with the bedding planes. The deposits strike north 60 degrees west and dip 65 degrees to the northwest. It has a maximum width of 40 feet. The ore consists of chalcopyrite, bornite, chalcocite in part oxidized to cuprite and malachite. The greater part of the mineralized quartzite contains about 4 per cent. copper, 6 ounces silver and .1 of an ounce of gold to the ton. The ore is worth from $9 to $10 per ton and goes to Butte and Tacoma.

Additional notes taken from Professional Paper, No. 62, on the Cœur d'Alene District, Idaho, by F. L. Ransome.

The production for 1905 was as follows: Lead, 123,830 tons; silver, 6,690,000 fine ounces; gold, 1,886 fine ounces. The production of copper for 1906 was 6,233,940 pounds. No zinc was produced prior to 1905. In 1905 the Success Mining Company built a mill at the Granite mine which, in 1906, worked an ore carrying 20 to 25 per cent. of zinc

turning out a middling carrying 45 per cent zinc. Other mines, such as the Sixteen-to-One, Hercules, Helena-Frisco, have become producers of zinc. On Pine Creek, southwest of Wardner, are a number of prospects, such as the Highland Chief, Douglas, Nabob and Surprise, which are possible sources of zinc ore. The production of zinc ore for 1906 amounted to 2,054,998 pounds.

The silver-lead deposits occupy two important areas, or belts, both of which are in the drainage basin of the South Fork of Cœur d'Alene River. One belt stretches from South Fork, near Mullen, northwest to Dobson Pass, at the head of Ninemile Creek. The other extends from Wardner beyond the western boundary of the mapped area. The deposits belonging to the larger, eastern belt are conveniently divisible into three groups: (1) The Mullen lodes, including those of Mill Creek and Hunter Gulch, near Mullen; (2) the Cañon Creek lodes, including those near the towns of Burke, Mace and Gem, and (3) the Ninemile Creek lodes, lying northwest of the crest of the narrow ridge that extends from Wallace to Tiger Peak. Outside of the two productive areas the district contains many deposits of lead-silver ore that are small or have never been thoroughly developed.

The principal mining companies operating on lead-silver ores are the Federal Mining and Smelting Company, owning the Tiger-Poorman mine at Burke, the Standard-Mammoth mine at Mace, and the Last Chance mine at Wardner; the Bunker Hill and Sullivan Mining and Concentrating Company, owning the Bunker Hill and Sullivan mines at Wardner; Larson and Greenough, owning the Morning mine near Mullen; the Hercules Mining Company, owning the Hercules mine near Burke; and the Hecla Mining Company, owning the Hecla mine, also near Burke. Certain other mines have contributed largely to the production in the past, although they are not at present being worked on the same profitable scale as the abovementioned mines. Such, for example, as the Helena-Frisco mine near Gem; the Granite and Custer mines on the west slope of Tiger Peak; the Gold Hunter mine near Mullen; the Sierra Nevada mine about a mile west of Wardner; and the Crown Point owned by the Cœur d'Alene Development Co., also west of Wardner, but just outside of the area mapped. The Wardner ores occur in the lower part

doubtless coalesce a few hundred feet below the surface, and the erosion of a few thousand feet of rock from the whole region would probably expose a large area of monzonite in the central part of the district with smaller outlying areas where at present no intrusive rock is known. In fact contact metamorphism on Dudley Creek indicates close proximity to the upper surface of a batholith.

Just south of the Cœur d'Alene District the Pre-Cambrian sediments are intruded and metamorphosed by granitic rocks and these occurrences help to link the Cœur d'Alene intrusions with the vast granitic mass in the central part of the state, from which the sedimentary cover has all been stripped away. The character of the Cœur d'Alene ores shows certain variations that are definitely related to the monzonitic intrusions. *E. g.,* the ores of the Granite and Sixteen-to-One mines, both of which are situated in the contact zone, encircling the largest of the monzonitic masses, contain abundant sphalerite, as well as galena, accompanied by pyrite, pyrrhotite, magnetite and chalcopyrite. The sulphides and magnetite are, in some places, intergrown with red garnet and are intimately associated with biotite and diopside. Several other mines show contact metamorphic minerals and very little siderite. Garnet occurs only in the ores within the contact zone of the monzonite. Siderite occurs only outside of the zone of metamorphic silicates. Sphalerite and pyrrhotite are most abundant in or near that zone and become less prominent constituents in deposits at a distance from the intrusive rock. Some of the deposits in the Prichard formation, even though situated many miles from the nearest exposure of monzonite exhibit certain of the contact metamorphic minerals. Such is the case with the Pine Creek prospects southeast of Wardner, where pyrrhotite and sphalerite are comparatively abundant. The presence of these minerals in the lowest stratigraphic horizon in the district indicates that the top of the batholith may not be very deeply buried. It is generally agreed that ores of the type found in the Granite mine have been deposited by solutions at high temperature and under heavy pressure. It is doubtful to what extent the depositing agent was an aqueous solution and to what extent a mixture of gases above their critical temperatures. That the hot solutions emanated from the

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

underlying monzonitic magma appears to be beyond reasonable doubt. In the case of the Granite mine, for example, situated in a narrow tongue of sedimentary rock almost surrounded by the monzonite, no other hypothesis to account for the source of the ores seems tenable. The solutions or gases as they issued from the monzonitic magma, at high temperature and under heavy pressure, first effected the metamorphism of the contact zone and deposited the ores rich in pyrrhotite and sphalerite associated with garnet and biotite. As the solutions penetrated farther through the fissured sediments, they deposited the sideritic galena ores, comparatively free from pyrrhotite and sphalerite.

References for the Cœur d'Alene District.

1. Professional Paper No. 62, U. S. G. S., by F. L. Ransome and F. C. Calkins.
2. Bull. No. 260, U. S. G. S., p. 274.
3. A. I. M. E., Vol. 33, pp. 235–271.
4. *Eng. Mg. Jour.*, Feb., 1888, p. 108.
5. *Mg. Mag.*, Vol. 12, pp. 26–32; by F. L. Ransome.

CHAPTER VIII.

GOLD AND SILVER DEPOSITS.

RANK OF STATES AND TERRITORIES IN PRODUCTION OF GOLD AND SILVER.
(Taken from "Mineral Resources of the United States" for 1907.)

Gold.	States.	Silver.	Deep Mines.	Placer Mines.	Total.
1	Colorada	1	51	591	642
2	Alaska	11	26	1,250	1,276
3	California	7	443	618	1,061
4	Nevada	5	216	13	229
5	Utah	2	165	14	179
6	South Dakota	12	30	6	36
7	Montana	3	305	131	436
8	Arizona	6	393	44	437
9	Idaho	4	145	214	359
10	Oregon	13	65	141	206
11	New Mexico	8	104	23	127
12	Washington	15	39	14	53
13	North Carolina	17	17	26	43
14	Philippines	27			
15	Georgia	21			
16	South Carolina	25	1	5	6
17	Alabama	22			
18	Wyoming	19	11	8	19
19	Virginia	23	6	1	7
20	Tennessee	14	4		4
21	Porto Rico				
22	Vermont	18	3		3
23	Texas	9	4		4
	Michigan	10	21		21
	Missouri	16			
	Illinois	20			
	New Hampshire	24	1		1
	Kentucky	26			

The following table shows that siliceous or dry ores, which in general may be considered as gold ores proper, furnished about 62 per cent. of the whole production, and that placers yielded approximately 26 per cent. The base-metal ores contributed between 9 and 10 per cent. of the total output, although the tonnage of these ores, as shown in a previous table, was exceedingly heavy. The copper ores yielded most of the gold from this source, while the lead ores only gave a small percentage, and the gold from zinc ores was insignificant in amount.

SOURCE OF GOLD IN 1907 IN STATES AND TERRITORIES, AS REPORTED FROM THE MINES TO THE UNITED STATES GEOLOGICAL SURVEY, BY KINDS OF ORE AND BY STATES, IN FINE OUNCES.

(Taken from "Mineral Resources of United States" for 1907.)

State or Territory.	Placers.	Dry or Siliceous Ores.	Copper Ores.	Lead Ores.	Zinc Ores.	Copper-Lead and Copper-Lead-Zinc Ores.	Lead-Zinc Ores.	Total.
Alabama	2.03	1,232.35	22.50	....	....	....	....	1,256.88
Alaska	797,752.13	133,751.31	4,540.37	....	....	....	....	936,043.81
Arizona	2,171.80	80,505.12	41,829.37	2,043.55	13.94	48.94	....	126,612.52
California	330,918.62	461,147.80	16,661.37	459.75	....	....	25.98	808.213.52
Colorado	4,877.65	949,448.09	8,827.39	40,725.26	589.35	1,303.81	1,695 59	1,007,467.14
Georgia	1,132.61	1,918.50	83.98	....	....	....	....	3,135.09
Idaho	17,265.28	34,409.04	5,894.26	3,113.52	....	....	72.60	60,754.70
Montana	16,866.77	99,731.08	30,772.08	6,465.48	5,135.10	....	....	158,970.51
Nevada	2,673.93	553,431.08	965.56	8,797.18	....	19,216.45	226.93	585,311.14
New Mexico	935.56	12,034.78	2,326.90	665.64	....	....	....	15,962.88
North Carolina	475.72	3,275.27	225.09	....	....	....	....	3,976.08
Oregon	16,031.77	37,861.99	734.24	....	....	....	....	54,628.00
South Carolina	44.75	2,604.51	....	....	....	....	....	2,649.26
South Dakota	44.70	200,140.19	....	....	....	....	....	200,184.89
Tennessee	....	....	185.04	....	....	....	....	185.04
Texas	....	.44	....	....	....	....	....	.44
Utah	438.35	42,853.89	158,154.83	46,170.73	....	123.77	18.06	247,759.63
Vermont	....	....	1.98	....	....	....	....	1.98
Virginia	5.66	395.22	.05	....	....	....	....	400.93
Washington	1,057.47	16,769.20	706.03	....	....	....	....	12,532.70
Wyoming	195.68	37.25	219.09	....	....	....	....	452.02
Total	1,192,890.28	2,625,547.11	272,150.13	108,441.11	5,738.39	20,692.97	2,039.16	4,227,499.16

Illinois, Kentucky, Philippines and Porto Rico not included.

The table also shows that the chief producers of gold from placers are Alaska and California. No other state produces a very large quantity of gold from placers. The states which yielded over 100,000 ounces from dry or siliceous ores rank as follows: Colorado, Nevada, California, South Dakota, Alaska and Montana. Compared with the preceding year decreases are common. The only gains are reported from Arizona, Georgia, Idaho, Nevada, North Carolina and Washington. This group includes many varieties of ore and several different methods of production are applied to them. The gold ores of California, Oregon and Alaska are as a rule free-milling, though concentration and cyaniding are very often combined with the simple amalgamation process. The ores of the Homestake mine in South Dakota fall into the same general class as do the Telluride and Ouray siliceous ores and ores from many scattering occurrences in Idaho, Colorado and Arizona.

The dry or siliceous ores further include the quartzose ores of Cripple Creek, Colorado, in which the prominent characteristic is the occurrence of large quantities of gold tellurides. These ores are partly smelted, partly chlorinated, and partly cyanided, all three processes being applicable.

There is a large class of dry ores which contain pyrite and other sulphides, and which are best treated by the smelting process with or without concentration.

Colorado contributes by far the largest quantity of these ores, among which those of Leadville are of particular importance.

Copper Ores: The copper ores yielded a small amount of gold compared with that yielded by placers and dry or siliceous ores. The important states rank as follows: Utah, Arizona, Montana, California, Colorado and Idaho. It will be seen that the Utah copper ores are by far richer in gold than those of any other state. In spite of its immense tonnage Arizona yielded only about one fourth of the production of Utah from this source. Most of this came from a single camp, the United Verde. Compared with 1906 the Butte copper ores declined in gold, and the Utah copper ores increased in gold due largely to the increased amount of rich ores from Tintic.

The copper ores which contain gold are chiefly of the

SOURCE OF SILVER IN 1907 IN STATES AND TERRITORIES, AS REPORTED FROM THE MINES TO THE UNITED STATES GEOLOGICAL SURVEY, BY KINDS OF ORE AND BY STATES, IN FINE OUNCES.
(Taken from "Mineral Resources of United States" for 1907.)

State or Territory.	Placers.	Dry or Siliceous Ores.	Copper Ores.	Lead Ores.	Zinc Ores.	Copper-Lead and Copper-Lead-Zinc Ores.	Lead-Zinc Ores.	Total.
Alabama	....	189	250	....	....	....	....	439
Alaska	75,526	22,203	52.055	....	....	....	....	149,784
Arizona	365	976,600	1,416,964	112,923	519	4,526	....	2,511,897
California	37,276	410,903	607,726	66,691	....	600	15,662	1,138,858
Colorado	1,906	7,409,999	143 103	2,357,981	52,173	98,382	1,166,232	11,229,776
Georgia	52	32	780	....	....	....	....	864
Idaho	5,518	843,077	536,007	6,817,839	....	....	2'4,990	8,415,431
Michigan	....	....	299,764	....	....	....	....	299,764
Missouri	....	....	....	....	....	....	25,692	25,692
Montana	2,909	1,697,045	7,163,038	328,385	....	126,178	....	9,317.605
Nevada	1,846	6,477,524	81,612	282,210	7,668	204,335	28,408	7,083,603
New Hampshire	....	....	....	174	....	....	....	174
New Mexico	173	542,252	115,323	45,393	....	....	2,403	705,544
North Carolina	53	722	20,892	....	....	....	....	21,667
Oregon	2,791	83,080	847	....	....	....	....	86,718
South Carolina	4	120	....	....	....	....	....	124
South Dakota	6	93,889	....	....	....	....	....	93,895
Tennessee	....	....	58,358	....	....	....	....	58,358
Texas	....	303,688	....	....	....	....	....	303,688
Utah	97	131,596	3,448,172	7,300,010	33,059	55,804	21,338	10,990,076
Vermont	....	....	3,814	....	....	....	....	3,814
Virginia	....	148	73	....	....	....	....	221
Washington	212	44,972	2,970	7,205	....	....	....	55,359
Wyoming	74	3	3,638	....	....	....	....	3,715
Total	126,808	19,038,042	13,955,436	17,318,811	93,419	489,825	1,474,725	52,497,066

Illinois, Kentucky, Philippines and Porto Rico not included in this table.

sulphide class. The sulphide ores are ordinarily concentrated and smelted; the oxidized ores are smelted without concentration. The gold is recovered by electrolytic refining of the copper.

Lead ores, copper-lead, and copper-lead-zinc ores: These different ores combined produce less than half as much gold as the copper ores. A little over one third as much gold was produced from lead ores as was produced from copper ores in 1907. The states producing gold from lead ores rank as follows: Utah, Colorado, Nevada, Montana, Idaho and Arizona. The first two states are far ahead of the others. The lead ores are chiefly of the sulphide class; large quantities of oxidized ores are, however, still furnished by the Tintic District.

Zinc Ores and Zinc-lead Ores: Only small amounts of gold are recovered from ores of this class. The chief production comes from Montana and Colorado.

The total silver product for 1907, as shown on page 139, was, as usual, divided chiefly between siliceous ores, copper ores, and lead ores. The proportion is, however, somewhat different from 1906. Only a small quantity is recovered from placers, most of which is credited to Alaska. In percentages of the total the division is as follows: Siliceous ores, 36.4 per cent.; copper ores, 26.8 per cent.; lead ores, 32.5 per cent.; copper-lead ores, 1 per cent.; lead-zinc ores, 3 per cent.; zinc ores, 0.2 per cent.; placers, 0.2 per cent.

Dry or Siliceous Ores: The states which are important in the production of silver from dry and siliceous ores rank as follows: Colorado, Nevada, Montana, Arizona, Idaho, New Mexico and California. The larger part of these ores are not silver ores proper, but are gold-silver ores. Only about 1,500,000 ounces were recovered from ores carrying exclusiverly silver values. Silver is practically a by-product of smelting ores and gold-silver milling ores. The production of Colorado was obtained from the gold-silver ores, partly free milling, from the Gilpin and San Juan regions, also from mixed ores, either pyritic or siliceous, which are concentrated and smelted and which also contain copper, lead or gold. The silver from siliceous ores in Nevada is chiefly derived from the sliceous gold-silver ores of Tonopah. The production of Montana is largely derived from the pure silver ores from

Granite County and mixed siliceous ores from other counties. The silver is recovered from siliceous ores by amalgamation or cyanide processes; some rich siliceous ores are smelted and the silver obtained by desilverization of lead bullion or by electrolytic refining of copper.

Copper Ores: The important silver-producing states from copper ores rank as follows: Montana, Utah, Arizona, California and Idaho. Compared with the production of 1906 Montana showed a decrease of 2,800,000 ounces; while Utah showed an increase of over 700,000 ounces due to the mining of an increase of the rich Tintic ores. Arizona showed a decrease of 300,000 ounces, the production coming mainly from the United Verde copper district.

Lead Ores: Of the states producing silver from lead ores Utah is the most important, the entire production coming from Park City, Tintic and Bingham ores. Idaho stood next and Colorado third in rank. As shown in the above table no other state even approached Utah, Idaho and Colorado in the production of silver from lead ores.

Copper-lead Ores: The production of silver from copper-lead ores, and from zinc ores, and zinc-lead ores is relatively unimportant.

GOLD AND SILVER.

With reference to geological distribution extraction and mode of occurrence Heinrich Ries speaks as follows in his "Economic Geology of the United States" concerning gold and silver.

"**Geological Distribution.**—Gold and silver ores have been formed at a number of different periods in the geological history of the continent, notably in the pre-Cambrian, Cambrian, Cretaceous and Tertiary ages, but Silurian, Devonian and Carboniferous gold deposits are not definitely known to exist in North America, although some of the Appalachian veins may be of this age. Silver ores show much the same geological distribution.

"**Extraction.**—Since gold and silver ores vary so in their mineralogical associations and richness, the metallurgical processes involved in their extraction are varied and often complex.

"Those ores whose precious metal contents can be readily extracted after crushing, by amalgamation with

quicksilver, are termed free-milling ores. This includes the ores which carry native gold and silver, and often represent the oxidized portions of ore bodies. Others, containing the gold as telluride or containing sulphides of the metals, are known as refractory ores, and require more complex treatment. These, after mining, are sent direct to the smelter if sufficiently rich, but if not they are often crushed and mechanically concentrated. The smelting process is also used for mixed ores, the latter being often smelted primarily for their lead or copper contents, from which the gold or silver is then separated. . . .

"Low-grade ores may first be roasted, and the gold then extracted by leaching with cyanide or chlorine solutions. The introduction of the cyanide and chlorination processes, which are applied chiefly to gold ores, has permitted the working of many deposits formerly looked upon as worthless, and in some regions even the mine dumps are now being worked over for their gold contents. . . .

"**Mode of Occurrence.**—Most of the gold and silver mined in the United States is obtained from fissure veins, or closely related deposits of irregular shape, in which the gold and silver ores have been deposited from solution. . . . Considerable gold and a little silver is obtained from gravel deposits. . . .

"The gold and silver-bearing fissure veins include two prominent types, viz.: (1) the quartz veins, and (2) the propylitic type, in which the metasomatic alteration of the wall rock is often propylitic, that is, accompanied by the formation of chlorite and epidote, but near the veins of sericite and kaolin. In the quartz-vein type silver is present usually in but small quantities, while in the propylitic type the silver often is an important constituent.

"While the mode of occurrence of gold and silver is quite variable, the character of the wall rock is equally so, gold and silver ores being found in either sedimentary or igneous rocks, and along the contact between the two, showing that the kind of rock exerts little influence, except perhaps where replacement has been active. On the other hand, the influence of locality is much stronger, for it has been found that many gold and silver-bearing deposits are closely associated with masses of igneous

rock, the most common of these being diorite, monzonite, quartz-monzonite, granodiorite, while true granites are rare as associates. A second large class of vein systems show a close association with lavas of recent age, and the telluride ores seem to favor these. . . .

"**Geographical Distribution.**—. . . The gold and silver occurrences of the United States and Alaska can be grouped under five areas, as follows:

1. The Cordilleran Region.
2. Black Hills, South Dakota Region.
3. The Michigan Region.
4. The Eastern Crystalline Belt.
5. Alaska.

"Of these the first, second and fifth are the most important, and the third is insignificant."

Without going into special detail with reference to the character of gold ores and mode of occurrence in these various regions, the matter can not be stated more concisely than by quoting directly from "Economic Geology of the United States," by Heinrich Ries.

Cordilleran Region.

"This area contains a number of important deposits of gold and silver ores, occurring chiefly in quartz veins, and to a lesser extent in gravels. There are also some representatives of the propylitic type.

"**Pacific Coast Cretaceous Gold-quartz Ores.**—Extending along the Pacific Coast from Lower California up to the British Columbia boundary there is a gold belt of great importance, which throughout its extent is characterized by quartzose ores and gold-bearing sulphides. The deposits belonging to this belt are especially important in California, but farther north, in Oregon and Idaho, the veins in many cases have been covered up by the lava flows of the Cascade Range, and those known in that region differ somewhat from the California deposits, in containing many mixed silver-gold ores and also veins carrying auriferous sulphides without free gold. The ores of this belt are all of undoubted Mesozoic age, and are accompanied by many extensive placer deposits, which have been derived by the weathering down of the upper parts of the quartz veins, the portions now remaining in

the ground representing probably but the stump of originally extensive fissure veins.

"Among the deposits of this belt two groups stand out in some prominence, namely, those of the so-called Mother Lode District and of Nevada County.

"**Mother Lode Belt.**—This includes a great series of quartz veins, beginning in Mariposa County and extending northward for a distance of 112 miles. The veins of this system break through black, steeply dipping slates and altered volcanic rocks of Carboniferous and Jurassic age, and since they are often found at a considerable distance from the granitic rocks of the Sierra Nevada, they have apparently no genetic relation with them. The veins, which occur either in the slate itself or at its contact with diabase dikes, show a remarkable extent and uniformity, due to the fact that in the tilted layers of the slates there lay planes of weakness for the mineral-bearing solution to follow. The ore is native gold or auriferous pyrite in a gangue of quartz, and the average value may be said to vary from $3 or $4 up to $50 or $60 per ton. The veins often split and some of the mines have reached a depth of several thousand feet.

"**Nevada County.**—In Nevada County the mines of Grass Valley and Nevada City are likewise quartz veins, but they occur along the contact between a granodiorite and diabase porphyry, as well as cutting across the igneous rock. Two systems of fault fissures occur, and in these the ore is found either in native form or associated with metallic sulphides. The width of the vein averages from two to three feet, and the lode ore generally occurs in well-defined bodies or pay shutes. The vein filling was deposited by hot solution, and while the wall rocks contain the rare metals in a disseminated condition, Lindgren believes that the ores have been leached out of the rocks at a considerable depth. The mines at Nevada City and Grass Valley have been large producers of gold and some silver. Placer mines have furnished a small portion of the product, but at the present day these latter are of little importance.

"In Oregon, the quartz veins are worked in Baker County, which is the most important gold-producing region of the state. Gold ores with sulphides in quartz gangue are worked in the Monte Cristo District of Washington.

"**Central Belt of Gold-Silver Ores.**—To the east of the Cretaceous gold-quartz belt there lies a second one, in the central and eastern part of the Cordilleran region, containing many gold and silver deposits of late Cretaceous or early Tertiary age, although they occur in older rocks, such as Carboniferous.

"**Mercur, Utah.**—The gold-silver mines of the Mercur district in Utah form perhaps the most important occurrences in this central zone. Here the Carboniferous limestones, shales and sandstones, representing about 12,000 feet of sediments, are folded into a low anticline. Near the center of the section is the great blue limestone, carrying an upper and a lower shale bed. Quartz porphyry has intruded the limestone, and at two places especially, spread out laterally in the form of sheets, on whose under side the ore is found, the silver ores under the lower sheet, the gold ores under the upper one, about 100 feet above the first. The silver ore is cerargyrite and argentiferous stibnite in a silicified belt of the limestone. The gold is native and occurs in a belt of residual contact clay, near northeast fissures cutting the limestone, being oxidized in places and accompanied by sulphides in others. The ore runs 1–19 ounces of silver per ton, and 2–3 ounces of gold, with a gangue of quartz, barite, limonite, and arsenical sulphides. The silver minerals are thought to have been deposited by heated solutions which came up along the igneous sheet sometime after its intrusion, and the deposition of the gold ore is believed to have taken place some time after the silver was deposited. Some doubt exists as to the exact source of the ascending waters, but in all probability they were derived from some deep-seated cooling laccolith. The ores are especially suited to the cyanide treatment.

"**Other Occurrences.**—The northward continuation of this belt of gold-bearing veins in Idaho and Montana presents somewhat different types of deposits, for there the veins are causally connected with great batholiths of Mesozoic granite; and while the veins resemble those of the Pacific Coast in the quartz filling and free gold contents, they differ from the latter in containing more silver, and often large quantities of sulphides with little free gold. In fact in their geologic relations they are intermediate between the quartz vein and propylitic type. Of special

prominence are those of Marysville, Montana, and Idaho Basin, Florence, etc., in Idaho. This difference is more marked in the Montana occurrences, in which the gold becomes subordinate and is obtained as a by-product in silver mining.

"**Eastern Belt of Tertiary Gold-Silver Veins.**—Of greater importance than the preceding class are the veins of Tertiary, mostly post-Miocene, age, which, according to Lindgren, are characteristic of regions of intense volcanic activity, and cut across andesite flows, or more rarely rhyolite and basalt. The veins may be entirely within the volcanic rocks, or the fissures may continue downward into the underlying rocks, which have been covered by the intrusive masses. Most of these Tertiary deposits belong to the propylitic class, showing characteristic alterations of the wall rock. The ores are commonly quartzose, and though either gold or silver may predominate, the quantities of the two metals are apt to be equal. Bonanzas are of common occurrence, and on this account the mines may be very rich, but short-lived; still, the workable ore in many extends to great depth, but is less rich than nearer the surface. Extensive and rich placers are rarely found in the Tertiary belt of veins, for the reason that the fine distention of the gold is not favorable to its concentration and retention in stream channels. Deposits of this type are worked in a number of states, including Colorado, Nevada, Arizona, New Mexico and Idaho. Colorado leads in the production of gold ores, for in no state are the Tertiary deposits of the propylitic type developed on such a scale.

"**San Juan Region.**—As an example of a more mixed type of ore of this class may be mentioned the San Juan region of southwestern Colorado, which includes the counties of San Juan, Dolores, La Plata, Hinsdale and Ouray, and is one of the most important gold and silver producing regions of the state, being noted for its persistent vertical veins, carrying gold, silver, and lead ores in varying proportions. Those in the vicinity of Rico are mentioned under silver-lead. Other important mining camps are Silverton, Creede, Telluride and Ouray.

The rocks of the San Juan district consist of a series of older sedimentaries, ranging from Algonkian to Cretaceous, buried under a complex of Tertiary volcanics, of

both acid and basic types. In the Silverton Quadrangle, for example, this volcanic series is several thousand feet thick and consists of tuffs, agglomerates, and lava flows. The more or less distinctly horizontal surface volcanics have been penetrated by later stocks of igneous rock, ranging from gabbro nearly to granite in composition, and by many small dikes of different types.

"The ore deposits form lodes, stocks, or masses (locally called chimneys), and replacement deposits. The lode fissures, which form the most important class, have been formed at several different periods and show varying strikes, but are often of great length, two or three miles being not uncommon, while some of the fractures probably extend continuously for as much as six miles. The ore-bearing minerals are pyrite and sulphides of copper, silver, lead, or zinc, in a gangue of quartz, barite, calcite, dolomite, rhodochrosite, etc. They have probably been deposited from aqueous solutions either in spaces or pores of the rock, or by replacement. The ores are mostly low grade, and require careful milling to yield profitable returns, but some are sufficiently rich to be shipped directly to the smelter.

"Another remarkable development of veins is found around Telluride, one of which, the Smuggler vein, has been traced four miles, and cuts the Tertiary volcanics. The ores are gold and silver in a gangue of quartz, with some rhodochrosite, siderite, calcite and barite. The ore bodies around Ouray differ from those around Silverton and Telluride in being found in the sedimentaries of the region, and form either fissure veins or replacements in quartzite or limestone connected with vertical fissures. Owing to the different degrees of replacibility shown by the wall rocks, the ore bodies present a most varied form.

"**Comstock Lode, Nevada.**—This lode, which is of historic interest, occurs near Virginia City, in southwestern Nevada, and is a great fissure vein, about four miles long, several hundred feet broad, and branching above, following approximately the contact between eruptive rocks, and dipping at an angle of 35 to 45 degrees. There is abundant evidence of faulting, which in the middle portion of the vein has amounted to three thousand feet. The lode is of Tertiary age, and contains silver and gold minerals in a quartzose gangue. One of the peculiar

features of the deposit is the extreme irregularity of the ore, which occurs in great "bonanzas," some of which carried several thousand dollars to the ton. The faulting is considered to have been quite recent, and the high temperatures encountered in the lower levels of the mine indicates that there is probably a partially cooled mass of igneous rock at no great depth.

"In former years the enormous output of this mine caused Nevada to be one of the foremost silver producers. It was discovered as early as 1858, and increased until 1877, after which it declined. Many serious obstacles were met with in the development of the mine, such that it has never become a source of much profit in spite of its enormous output. In 1863, at a depth of 3,000 feet, the mine was flooded by water at a temperature of 170° F., due to a break in the clay wall; and to drain it $2,900,000 were spent in the construction of the Sutro Tunnel, which was nearly four miles long, but by the time it was completed the workings were below its depth. A second difficulty was the encountering of high temperatures in lower workings, these in the drainage tunnel mentioned being 110° to 114° F. The mine is credited with a total production of $368,000,000. In recent years its output has been slowly increasing again.

"Other occurrences of the propylitic type are found in Gilpin, Boulder and Clear Creek counties, Colorado.

"In Arizona the Commonwealth Mine of Cochise County is probably referable to this group, as is also the Congress mine

"Fissure veins associated with Tertiary eruptives are found in Owyhee County, Idaho, in the Monte Cristo district of Washington, and the Bohemia district of Oregon. The auriferous copper veins of Butte, Montana, also belong in this group, but since they are more important as producers of copper, they are described under that head."

Black Hills Region.

"The gold-bearing ores are found chiefly in the northern Black Hills, and include: (1) Auriferous schists in pre-Cambrian rocks; (2) Cambrian conglomerates; (3) refractory siliceous ores; (4) high-grade siliceous ores; and (5) placers. Of these the first and third are the most important.

"The surface placers, being the most easily discovered, were developed first, followed by the conglomerates at the base of the Cambrian. These are found near lead, occupying depressions in the old schist surface, and the material is thought to have been derived from the reef formed by the Homestake ledge in the Cambrian sea. These deposits are of interest as being probably the oldest gold placers known in the United States. The fact, however, that the matrix of the gold-bearing portion of the conglomerate is pyrite rather than quartz, and the occurrence of gold along fractures stained by iron, has led some to believe that the gold has been precipitated chemically by the action of the sulphide and is not a detrital product."

" **Homestake Belt.**—The gold ores of the Homestake belt, which are the most important in the Black Hills, occur in a broad zone of impregnated schists, containing many quartz lenses, alternating with dikes of fine-grained rhyolite, which also formed sheets in the Cambrian sediments overlying the schists, and now remains as a resistant cap on many of the surrounding ridges. The ore, which is all low grade, averaging $5 to $6 per ton, is usually a mixture of quartz, pyrite, and occasionally other minerals having no definite connection with it, occupying a zone in the Algonkian rocks which shows greater hardness, irregularity of structure, and mineralization than the surrounding schists. The boundaries are poorly defined, and superficial examination may fail to distinguish between ore and barren rock. In the upper levels the ore seems to be with the dikes, but diverges from them in depth, and there is apparently no genetic relation between the two. In the earlier days the ore encountered was oxidized and free-milling, but the appearance of sulphides with depth has necessitated the introduction of the cyanide method of extraction. In spite of the low grade of its ores the Homestake mine, due to proper management, stands out as one of the richest mines of the world, its monthly production amounting to about $300,000. The ore was originally worked as an open cut, but later by underground methods."

References for Black Hills Region.

1. "Economic Geology of the United States," by Henrich Ries.
2. *Eng. and Mg. Jour.*, Vol. 75, pp. 563–564, by G. C. Hewett.
3. S. Dak. School of Mines Bull. No. 5, pp. 1–77, by C. H. Fulton. (Discusses the cyanide process.)
4. A. I. M. E., Vol. 30, pp. 278–285.
5. Int. Mg. Cong., 4th Session, pp. 97–100, by C. C. O'Harra.
6. S. Dak. Geol. Surv. Bull. No. 3, pp. 131, by C. C. O'Harra.
7. *Mg. and Sci. Press*, Vol. 87, pp. 166–167, 187–188, 205, 221–222, by J. D. Irving.

Siliceous Cambrian Ores.—"A second important type is the refractory siliceous Cambrian ore found in the region between Yellow Creek and Squaw Creek, and yielding about two thirds as much gold as the Homestake. The deposits, which occur as replacements in a siliceous dolomite, are found at two horizons, one immediately overlying the basal Cambrian quartzite, and the other near the top of the Cambrian series. The ore forms flat banded masses known as shoots, and varying in width from a few inches to 300 feet. It is overlain by shale or eruptive rock, and associated with a series of vertical fractures, made prominent by a slight silicification of the wall rock. These fractures, which are termed *verticals*, are supposed to have conducted the ore-bearing solutions.

The ore is a hard, brittle rock, composed of secondary silica, with pyrite and fluorite, and at times barite, wolframite, stibnite, and jarosite. Its contents range from \$3 or \$4 per ton to, in rare cases, \$100 per ton, with an average of \$17. Other, but less important, siliceous ores occur in the Carboniferous rocks."

Michigan Region.

A small amount of gold has been found in a quartzose zone in schists, near Marquette, Michigan, but the area is of little importance.

Gold in the East.

The following, pertaining to eastern gold ores, is taken chiefly from an article in Vol. 25 of the A. I. M. E., by H. B. C. Nitze and H. A. J. Wilkins.

The gold fields of the southern Appalachians are situated in the area of crystalline rocks, extending from near

Washington southwest through the Piedmont and Mountain regions of Maryland, Virginia, North Carolina, Tennessee, South Carolina and Georgia, to near Montgomery, Alabama.

The greatest width of the belt as a whole is attained in North Carolina, South Carolina and Georgia. There it is 100 to 150 miles in width, narrowing to the northeast in Virginia and Maryland, and to the southwest in Alabama. The rocks are Archean, Algonkian and, in part, Paleozoic, covered by coastal plain and in places by Jura Trias. They are bordered on west by Paleozoic rocks. The rocks of the gold belt are decomposed to depth often reaching 50 to 100 feet. For this rotten rock Becker suggests the term saprolite. For geological reasons and for convenience the gold belt of southern Appalachians is differentiated into six minor belts:

1. Virginia Belt.
2. East Carolina Belt.
3. The Carolina Belt.
4. The Southern Belt.
5. The Georgia Belt.
6. The Alabama Belt.

1. The Virginia Belt.—This belt extends from Montgomery County, Maryland, southwest to the North Carolina line. It is from 9 to 20 miles wide. The rocks of the area consist of mica gneisses and schists, often garnetiferous talcose and chloritic. The prevailing strike of the schists is N. 20° to 30° E. and the dip is southeast.

The auriferous quartz veins conform to the strike and dip of the schists. The veins are irregularly lenticular and vary in thickness from a few inches to several feet. The wall rock is often impregnated with auriferous pyrite to considerable extent. Some lodes are very persistent, *e. g.*, the Fisher lode in Louisa County is opened for a distance of five miles to a maximum depth of 220 feet. The gravel placer deposits are in every way similar to those of other gold regions. The auriferous copper ores of Ashe and Watauga County, North Carolina, also belong here.

2. Eastern Carolina Belt.—This is a small and narrow area in Halifax, Warren, Nash and Franklin Counties. It is covered on the east by coastal plain and bordered on the

west by Louisburg granite. The country rock is diorite sheared to chlorite schist. Strike of schists, N. 50° to 60° E. Quartz veins occur (1) as lenses from minute size to 12 inches in thickness, cutting the schists; (2) as a reticulated network in the massive rocks.

3. Carolina Belt.—This is one of the most extensive and important gold belts in the southern Appalachians. It is situated in the central piedmont region and extends from the Virginia line, southwest, across the central part of North Carolina into the northern part of South Carolina, when it sinks beneath the coastal plain. The belt varies in width from eight to fifty miles. It is bounded on the west by an extensive granite area and on the east by Jura Trias and coastal plain formations.

The gold-bearing rocks are composed of metamorphosed slates and schists, ancient volcanic, and plutonic rocks, siliceous magnesian limestones and pre-Jura Trias slates. The gold ores occur in two principal structural forms: (1) Quartz fissure veins, (2) pyritic impregnations, accompanied by irregular, stringer-like, and lenticular quartz intercalations in the country schists and slates.

The age of the ore deposits is later than the force which produced schistosity, as fragmental inclusions of sheared country are not rare in the quartz. The fissures, as a rule, follow closely the planes of cleavage in the schists. A very common occurrence of the ores is that of irregular, finely-divided disseminations of auriferous sulphurets and fine gold, accompanied by small stringers and lenses of quartz in the country slate and schists, which are usually silicified at least to some extent. The form of deposits bear close resemblance to the Scandinavian fahlbands which e are d~~i~~scribed as belts of schists impregnated with sulphides. The gravel placers of the Carolina belt do not differ from those of similar deposits in other gold regions.

Genesis of the Ores.—There is no definite proof of metasomatic formation. The most reasonable explanation is that of ascension of heated carbonated and alkaline waters, carrying silica, metallic elements, and sulphides in solution, and deposition of the mineral contents in open spaces by relief of pressure, reduction of temperature and perhaps by certain chemical reactions. The sulphurets consist of pyrites chiefly with chalcopyrite, galena, arsenopyrite, and zinc blende, occurring locally. Copper ores in

some of the North Carolina mines are auriferous to such an extent as to make them valuable for gold also. Tellurides have been found in small quantity, as at Kings Mountain mine, North Carolina. The more common gangue minerals, besides quartz and sulphurets, are chlorite, barite and carbonates.

Age of the Ores.—Ore deposition took place subsequent to schistosity. The occurrence of gold in the Jura-trias conglomerates show that the origin of the gold must have been pre-Jura-triassic. The presence of gold-bearing fissure veins in the Monroe slates shows that their age must be Algonkian or later. They are, in all probability, of Algonkian age.

4. The South Mountain Belt.—This belt is situated in the western part of North Carolina and takes its name from South Mountain, an eastern outlyer of Blue Ridge. The principal mining region is twenty-five miles long and from ten to twelve miles wide.

The country rocks are chiefly biotite and hornblende gneisses and schists. They are often garnetiferous and contain also many rare minerals such as zircon, monazite and xenotime. The schists are metamorphosed granites and diorites. The strike of the schistosity is N. 10° to 25° W. and the dip is 20° to 25° N. E.

The gneisses contain isolated masses of pyroxenite and amphibolite often altered to talc and serpentine. Pegmatites are also common in the schists.

The auriferous quartz veins form a system of parallel fissures of remarkable regularity, striking N. 60° to 70° E. and dipping 70° to 80° N. W. Their thickness varies from that of a knife edge to that of four feet. The great majority are from one to threee inches. The ore is quartz, usually of a milky white color, often stained, and is cellular from the decomposition of sulphurets. The sulphurets are pyrite, galena, chalcopyrite and zinc blende. All observations go to show that the vein matter is formed from ascending mineralized solutions.

Placer Deposits.—These furnish the principal mining ground of the South Mountain region. The placer deposits are of three classes: (1) The gravel deposits of the stream and bottom lands, deposited by fluviatile action; (2) the gulch and hill-side deposits, or accumulations due to secular disintegration and motion induced by frost ac-

tion and gravity; (3) the upper decomposed layer of the country rock in place.

5. **The Georgia Belt.**—This belt is next to the Carolina belt in economic importance. It extends from the northeast corner of the state southwest through Dahlonega and thence to the Alabama line in the vicinity of Tallapoosa. It lies in the piedmont region of the state southeast of the Blue Ridge.

The country rocks consist of mica and hornblende gneisses and schists, which probably represent sheared granitic and dioritic rocks. The prevailing strike is N. 20° to 30° E. and the dip from 30° to 60° S. E. The rocks are often garnetiferous and contain such accessory minerals as monzonite. The schists are often intruded by diabase dikes.

Ore Deposits.—Certain bands of the gneisses and schists have been fissured and filled with gold-bearing quartz and sulphurets. The fissures are usually parallel to the schistosity of the rocks. They are often aggregated in a zone of numerous, narrow and discontinuous lenses and stringers through more or less definite bands of the gneiss which, taken altogether, form the vein.

6. **The Alabama Belt.**—This belt might be considered as a continuation of the Georgia belt. It comprises an area of about 3,500 square miles, situated in the crystalline rocks of Cleburne, Randolph, Talladega, Clay, Tallapoosa, Chambers, Coosa, Elmore and Chilton Counties. It is the southwest extremity of the southern Appalachian gold field.

The gold-bearing rocks consist of shales, gneisses, schists and granite. The prevailing strike is northeast and the dip is southeast. The auriferous quartz veins are interlaminated in these rocks and coincide imperfectly with the strike and dip of the schistosity. The quartz is usually glassy; the sulphurets are in the main pyrite, and the gangue minerals are those of usual occurrence in gold-bearing quartz veins elsewhere.

References for the Appalachian Gold Belt.

1. A. I. M. E., Vol. 25, pp. 661–716, by H. A. J. Wilkins.
2. "Economic Geology of the United States," by Henrich Ries.
3. 16th Ann. Rept., Pt. III, pp. 251–333, by G. F. Becker.
4. Bull. 213, U. S. G. S., pp. 57–63, by Eckel.

5. *Eng. and Mg. Jour.*, Aug. 17, Sept. 21, Nov. 2, 1901.
6. A. I. M. E., Vol. 33, pp. 119–125, by W. H. Fluker.
7. Bull. No. 4, Geol. Surv. of Ga.
8. Bull. Geol. Surv. of N. C., 1897.

Cripple Creek District.—The following on the Cripple Creek District is taken from an article by W. Lindgren and F. L. Ransome from Bull. 260, U. S. G. S., and quoted in part directly as indicated below. The Cripple Creek District, in Teller County, near the central part of the State of Colorado comprises principally a group of rounded bare hills forming part of the high plateau extending southwestward from Pikes Peak. The principal mines are only about ten miles distant from that prominent landmark. The principal elevations of the district range from 9,000 to nearly 11,000 feet above sea level, the highest point in the district being Trachyte Mountain (10,836 feet). Bull Hill and Bull Cliff are but slightly lower. "The drainage is chiefly southward toward the Arkansas River. The district contains two important towns. Cripple Creek is situated on the northwest side of the producing area, while Victor, three miles distant, lies on the southwest edge of the same area. Two railroads connect the district with Colorado Springs, the Colorado Midland circling around the north side of Pikes Peak, while the Short Line descends to the valley along the picturesque eastern slope of the same mountain. The Florence and Cripple Creek Railroad runs southward to Florence, in the Arkansas Valley. An excellent system of electric car lines connects the towns with all the important mines.

Geology.—"The Cripple Creek Hills lie near the eastern border of an elevated and much dissected plateau, which slopes gently westward for forty miles. . . . The prevailing rocks of this plateau are granites, gneisses and schists. The granites inclose masses of Algonkian quartzite, and are therefore post-Archean; but they are older than the only Cambrian sediments known in Colorado and on the Cripple Creek map have been indicated as Algonkian. During Tertiary time volcanic eruptions broke through these ancient rocks at several points and piled tuffs, breccias and lavas upon the uneven surface of the plateau. The eruptive rocks of the Cripple Creek District are the products of one of the smaller isolated volcanic centers

of this period, a center characterized by the eruption of phonolite, which does not occur elsewhere in this general region. The most voluminous products of the Cripple Creek volcano now preserved are tuffs and breccias. They occupy a rudely elliptical area in the center of the district, about five miles long in a northwest-southeast direction and about three miles wide. According to Cross, these breccias and tuffs rest in part upon an earlier flow of andesite, but mainly upon an unevenly eroded surface of the granites and schists, although along the southwest edge of the area the contact was found to be so steep as 'to support the idea that the central vent or vents of the volcano were adjacent to this line. . . .' The most characteristic massive rock of the Cripple Creek volcano is phonolite, which was erupted at several periods and more abundantly than any other type. Is occurs as dikes and masses, not only in the breccia, but in the surrounding granitic rocks.

"'The general succession of igneous rocks, according to Cross, is as follows: The earliest rocks were andesite containing some orthoclase. Then came a series of allied phonolitic rocks, rich in alkalies and moderately rich in silica, together with some andesites. Among them are trachytic phonolite, nepheline-syenite, syenite-porphyry, phonolite, mica-andesite, and pyroxene-andesite. Phonolite was erupted at several periods. The nepheline-syenite he considered as probably younger than the trachytic phonolite. At the close were intruded a small number of narrow dikes of basic rocks, the so-called basalts, which contrast very markedly with the phonolite.'"

Economic Geology.—From mineral resources of the United States we learn that the Cripple Creek District produced, in 1891, only $449 in gold, with no silver. In 1907 the district produced $10,913,687 in gold and 872,204 fine ounces in silver. Teller County produced more than four times as much gold as any other county in Colorado, in 1907, and the production came exclusively from the Cripple Creek District. Lindgren and Ransome continue by saying: "A circle of three miles radius described from the summit of Gold Hill would include all deposits of known or prospective value, while the really important mines would be embraced by a circle of about half that radius, with its center near the summit of Raven Hill. That scattered

deposits of greater or less value may be found in outlying portions of the district is by no means improbable. But the close dependence of the typical Cripple Creek ores upon the main volcanic center, and the consequent remarkable compactness of the gold-bearing area, are features highly characteristic of the district and are likely always to remain so."

Underground Development.—"At the time of the earlier survey the deepest shafts, those of the Moose, Pharmacist, and Anna Lee mines, were down only about 400 feet, while few of the other mines were over 200 feet in depth. Many subsequently prominent mines were then mere prospects or had not been located. The deepest shaft, at present (in 1904), is the Lillie, which is over 1,500 feet deep, although the Stratton's Independence shaft, 1,400 feet deep, has the lowest sump in the district. The American Eagle shaft is nearly as deep as the Lillie, while there are about twenty other shafts over 1,000 feet in depth, and at least 100 shafts deeper than the deepest workings existing in 1894. . . ."

"**Character of the Ores.**—No more concise and at the same time complete statement of the character of the ores, structural features, and types of ore bodies can be given than by quoting directly as follows from an article by Lindgren and Ransome in Bulletin No. 260, of the U. S. G. S.

"The characteristic feature of the Cripple Creek ores is the occurrence of the gold in combination with tellurium, chiefly as calaverite, but partly also as the more argentiferous sylvanite, and probably to a minor extent as other gold, silver and lead tellurides. The tellurides are frequently associated with auriferous and highly argentiferous tetrahedrite, with molybdenite, and occasionally with stibnite. While these minerals have not yet been closely studied, preliminary examination indicates that their contents in gold are due to an intimate mechanical mixture of tellurides. Pyrite, while widely disseminated through the country rock and of common occurrence in the fissures, is rarely sufficiently auriferous to constitute ore. Such of the pyritic ores as have been tested reveal the presence of tellurium, indicating that the ore is a mixture of pyrite and gold-silver tellurides. Galena and sphalerite occur in small quantities in many of the mines,

but rarely contain enough of the precious metals to form ore. Native gold appears to be absent from the telluride ores, except as it may be set free by the oxidation of these tellurides.

"The usual gangue minerals of the ores are quartz, fluorite and dolomite. Roscoelite and rhodochrosite are also found in places. Celestite, or sulphate of strontium, while never present in large amount, frequently occurs as little acicular crystals in the quartz vugs of the lodes. Calcite occurs interstitially in much of the breccia near the ore-bodies, but is rarely found in distinct crystalline form with the ore minerals. Secondary potassium feldspar is common in the ores; it is especially abundant in the ores inclosed in granite, particularly those in the Pikes Peak type. This feldspar has the composition of orthoclase or microcline, and is formed by the recrystallization of the original potassic feldspar contained in the rocks. In the granitic ores of the Stratton's Independence, Portland, Ajax and Elkton mines this secondary feldspar is the principal gangue mineral.

"Oxidized ores, while still worked in many properties, are of relatively less importance than when Penrose described the district. They contain the characteristic dull gold, often in pseudomorphous skeletons, resulting from the oxidation of the tellurides, associated with tellurite (tellurium dioxide), emmonsite or durdenite (both hydrated ferric tellurites), and probably other oxidized compounds of tellurium and iron. These minerals occur in association with kaolin, alunite and ferruginous clays. The deep workings of the present day show that kaolin is always connected with oxidation, and is not a product of the original mineralization of the district, as was supposed by Penrose.

"The Cripple Creek ores, as a rule, contain very little silver, the average proportion being about 1 ounce of silver to 10 ounces of gold. In the Portland and Stratton's Independent mines the proportion is very much less, the silver from the Portland in 1901 amounting to only 2.4 ounces for each 100 ounces of gold. In the Blue Bird, Doctor-Jack Pot, Conundrum, Pointer, and other mines containing notable amounts of tetrahedrite or galena, the proportion of silver rises considerably above the average.

"The average value of the Cripple Creek ores lies prob-

ably between $30 and $40 per ton. In some of the larger mines the average value sinks to about $25 per ton. From a lower economic limit of about $12 per ton the values of individual shipments swing through a wide range up to ores carrying $3,000 to $4,000, or even $8,000 per ton. Occasionally smaller amounts—one or two tons—have yielded as much as $50,000 per ton.

"**Structural Character of Deposits.**—With few exceptions the ore bodies, of whatever shape, are causally connected with fissures, and most of them constitute fissure veins of various types. The fissure system of the district appears to radiate from a point near the northern limit of the volcanic area. In the eastern part the prevailing directions are northwest or north-northwest, gradually changing to a northerly strike in the southern portion and to predominant north-northeast or northeast courses in the western side of the district.

"Individual veins are rarely over half a mile in length, but linked vein systems often extend for a mile in the same direction. The dip is generally very steep. The movement along these fissure planes appears in all cases to have been very slight. The fissures charged with ore are sometimes simple veins with one fracture plane; much more commonly, however, they are composite veins or lodes which consist of several closely spaced and frequently linked fissures, all more or less ore-bearing. A better expression for this structural type as it appears in Cripple Creek is the term 'Sheeted zone.'"

"**Types of Deposits.**—The most important types of auriferous ore bodies occurring in the district are:

"1. Tabular in form and strictly following simple fissures or sheeted zones. A subtype comprises lodes in which the sheeted zone follows 'basalt' or phonolite dikes.

"2. Irregular bodies adjacent to fissures and formed by replacement and recrystallization of the country rock—usually granite.

"These types are not always sharply distinct, but may be connected by deposits of intermediate character.

"All the ore bodies, of whatever type, exhibit certain common features which serve to distinguish the deposits of Cripple Creek from those of most other mining districts. In the first place, the actual openings in the rocks available for the deposition of ore are, as a rule, remark-

ably narrow. In the second place, the amount of material carried in the mineralizing solutions and deposited as gangue and ore minerals was comparatively small. In consequence of these two conditions, the district contains no such massive veins, solidly filled with quartz or other vein minerals, as are characteristic of the San Juan region in Colorado or the Mother Lode region in California. Even the small fissures of the Cripple Creek District are rarely completely filled, but exhibit a characteristic open or vuggy structure. Where the fractures are of unusual width, or where the rocks are extensively shattered, as in the Midget or Moose mines, the small volume of available vein matter is particularly noticeable. The walls of such fractures and the fragments of the shattered rock are usually merely coated with a thin deposit of quartz, fluorite, and other minerals. As the rich tellurides were usually among the minerals last to form, and are particularly abundant on the walls of the vugs, it is probable that had quartz, fluorite, or other gangue minerals been more abundantly deposited the ores would have been of much lower grade.

"*Sheeted Veins.*—The mineralized sheeted zones constitute the most characteristic deposits of the district and occur in practically all the rocks, although particularly common in breccia. They consist of a varying number of narrow, approximately parallel fissures, together composing a sheeted zone that may range from a fraction of a foot to 50 or 60 feet in width.

"As a rule, the fissures are mere cracks, showing no brecciation, slickensiding, or other evidence of tangential movement of the walls. Usually the tellurides are exclusively confined to the narrow fissures, and cracks, and rarely, in this type of deposit, constitute a replacement of the country rock. The accompanying Fig. 13 shows the association of a sheeted zone with flat fissures developed in the breccia at the contact with phonolite. The rocks in the vicinity of the fissures are partly replaced by dolomite, pyrite, and a little fluorite. The fissures are not, in general, planes of faulting. Appreciable movement has undoubtedly occurred in some instances, but the displacement probably rarely exceeded one or two feet.

"Although found most abundantly in the breccia or trachytic phonolite, sheeted zones and single fissures are

often well developed in the granite, as in the El Paso, C. K. & N., and Gold Coin mines. While in some of these lodes the ore minerals are as plainly confined to the fissures as in the breccia, in other cases the ore to some extent permeates the granite alongside the fissure, this constituting a deposit intermediate in nature between types 1 and 2. They also frequently follow phonolitic dikes, the general tendency of these dikes to develop a slaty parting parallel to their walls being particularly favorable to the production of a well-defined sheeted zone when the direction of fissuring happens to coincide with that of the dike.

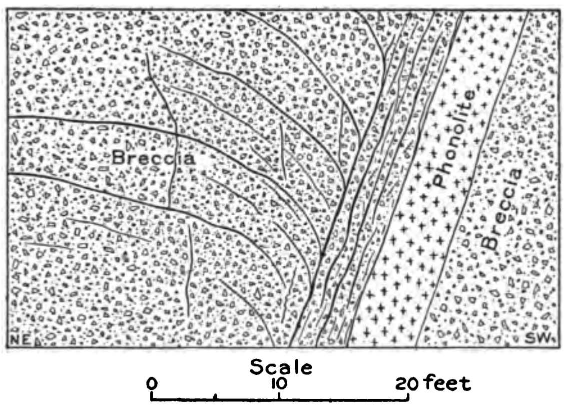

Fig. 13. Sheeted zone of the Apex vein, Ajax mine. (From U. S. Geological Survey, Professional Paper, No. 54, p. 162, Fig. 9.)

"The metasomatic alteration accompanying these sheeted zones is surprisingly slight, and consists of a partial replacement of the breccia, phonolite, trachytic phonolite, or 'basalt' by dolomite and pyrite accompanied by a small amount of sericite and a little secondary potash feldspar. The alteration in granite exhibits a somewhat different phase, described in a subsequent paragraph.

"Not all the sheeted zones carry ore, nor is the ore of a productive sheeted zone necessarily coextensive with the fissuring. The ore occurs in pay shoots up to 2,000 feet in length and 1,000 feet in depth, but usually very much smaller than is indicated by these limits.

"**Replacement Deposits in Granite.**—The replacement deposits in granite all occur in close proximity to the contact with the breccia, and are well developed in the Elkton (Thompson), Ajax, Independence and Portland mines. Although these bodies of ore are related to fissures and occur particularly where several fissures intersect, or where they meet a dike, the ore is not confined to the actual fractures. The rock in the vicinity of these fissures is often extensively altered. The most obvious characteristic of the metamorphosed rock is a porous texture and a change of the reddish color of the normal granite to grayish or greenish tints. Closer examination shows that the rock, consisting originally of microcline, oligoclase, quartz, and biotite, may be completely recrystallized as a porous, vuggy aggregate of secondary orthoclase (valencianite), quartz, fluorite, pyrite, calaverite, or sylvanite, and, in exceptional cases, sphalerite and galena. The ore minerals are partly enclosed in the other secondary minerals, but occur most abundantly, with little projecting crystals of fluorite, quartz, and valencianite, on the walls of the irregular pores characteristic of the altered rock.

"While the replacement deposits in granite are important because of their size and the readiness with which the ore may be mined free from waste, the ore itself is usually of lower grade than that formed in the fissures of the sheeted zones."

"**Mineralized 'Basalt' Dikes.**—The ore bodies formed by the mineralization of basic dikes are in some ways closely related to the sheeted zones already described. Like the phonolite dikes, the 'basalt' exhibits a pronounced tendency to split into thin sheets parallel with the dike walls. Normally the minute fissures so formed are filled with veinlets of calcite and contain no ore. When, however, a zone of fissuring coincides with the dike the latter may be traversed by veinlets of quartz and fluorite carrying sylvanite or calavarite, while the body of the dike may be impregnated with pyrite. Such ore differs from that of the usual sheeted zones in breccia or phonolite in that the tellurides are not so clearly confined to the actual fissures, but appear to some extent to permeate the rock with the pyrite. The richest portion of the ore, however, undoubtedly occurs in the small veinlets in the dike, and

usually near one or both walls, where the fissuring is best developed.

"**Depth of Oxidized Zone.**—At a few points, as in the Abe Lincoln and El Paso mines, tellurides are found almost at the surface. It is much more common, however, to find an upper zone, from 200 to 400 feet deep, in which free gold prevails and which gradually changes to the zone of pure telluride ores. As may be expected from the varying surface form and conditions of drainage, there is great range in the depth attained by oxidation. Partial oxidation extends in many mines to a depth of over 1,000 feet, especially along the often more or less open fissures.

"**Relations of Ore Bodies to Depth.**—It is well known that the payable ores in auriferous lodes are rarely equally distributed in the lode, but form tabular bodies of more or less regular outline. The projections of these bodies on the plane of the lode often appear as elongated areas with greater vertical than horizontal extent. The ore bodies or shoots of Cripple Creek show great similarity to those of other gold-bearing veins; their limit in depth is usually as well defined as their extent in a horizontal direction.

"In the case of shoots reaching the surface, a certain part has probably been removed by erosion. The shoots which distinctly began below the surface show the normal form of the ore bodies to be elongated, vertical, or pitching sharply northward, the ratio of vertical to horizontal extension varying from $1\frac{1}{2}:1$ to $5:1$. Some of these shoots are however, of about equal dimensions vertically and horizontally, while in a few the horizontal dimension is the greater.

"Of the known ore bodies, as few exceed 1,000 feet in length, so very few exceed 1,000 feet in depth or extend more than 1,000 feet from the surface. Speaking broadly, explorations below that limit have not proved very satisfactory. Drawing the lines a little closer, it may be said that in proportion to the amount of exploration the upper 700 or 800 feet have yielded more than the interval from that limit to the lowest levels reached—about 1,500 feet. It must not be overlooked, however, that four or five mines still have good ore bodies at a depth of 1,200 to 1,400 feet from the surface. The de-

velopment of the next year or two will probably give a safer basis for generalization.

"Roughly speaking, the above-mentioned distribution holds good for any elevation within the district. In other words, the principal productive zone everywhere occupies the space from the surface down to about 1,000 feet below it, and its lower limit thus forms a curved surface approximately parallel to the surface of the ground.

"The general features of the vertical distribution of the known ore bodies recorded above have of late years received more or less recognition, and there has been a decided tendency to attribute them to a process of secondary enrichment effected by waters moving generally downward from the surface. It has been supposed that such waters have carried down a part of the auriferous contents of those portions of the lodes now removed by erosion and have enriched originally lean pyritic ores by the secondary deposition of gold and silver tellurides and argentiferous tetrahedrite, with associated gangue minerals.

"Careful study of Cripple Creek ore deposits has failed to discover that the hypothesis of secondary enrichment is supported by crucial evidence. The minerals are not arranged in any discoverable definite sequence, nor does the present investigation find much to support the view that the rich telluride ores, as a rule, pass with increasing depth into low-grade pyritic ores. Frequently such ore as occurs below a depth of 1,000 feet is precisely the same in character as ore found within 100 feet of the surface. Tetrahedrite, which has been regarded by some, without definite proof, as a secondary mineral, occurs sporadically throughout the district and at all depths reached by present workings. The richest ore does not uniformly occur immediately below the oxidized ore. There is, in fact, little indication of enrichment in the oxidized zone such as is so often found in gold-quartz veins of the normal type. Frequently the fresh telluride ore is extremely rich, and high-grade pockets occur impartially in oxidized and fresh portions of the veins. Neither would it be correct to say that there is a gradual decrease in the value of ore in depth. It is quantity, not value, which decreases.

SUPPLEMENTARY NOTES.

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"While it is certain that pyrite, and possibly other minerals, have formed at more than one period during the mineralization of the district, and while it is equally clear that in general the rich tellurides were the last of the ore minerals to be deposited, there is apparently no evidence that any one of these minerals has been formed by enriching solutions at the expense of primary minerals. So far as definite conclusion is warranted in an investigation as yet incomplete, it appears that the unoxidized ore deposits of the Cripple Creek District represent the product of one general period of mineralization and that they have not been appreciably modified by secondary enrichment during the subsequent erosion of the region."

References for the Cripple Creek District.

1. Bull. 260 U. S. G. S., p. 85, by W. Lindgren and F. L. Ransome.
2. "Economic Geology of the United States," by Heinrich Ries.
3. Professional Paper No. 54, U. S. G. S., by W. Lindgren and F. L. Ransome.
4. *Proc. Col. Sci. Soc.*, Jan. 8, 1894, by R. Pearce.
5. 16th Ann. Rept. U. S. G. S., Pt. II, pp. 13–209.
6. Pikes Peak, Folio No. 7, U. S. G. S., by W. Cross.
7. I. M. M. I., Pt. 3, Vol. 8, pp. 49–96, by T. A. Rickard.
8. A. I. M. E., Vol. 26, p. 151, by E. S. Keeves.

Alaska.

The following is quoted from Ries' "Economic Geology of the United States."

"Although gold has been known to occur in Alaska since the early part of the century, and was even worked in 1860, its production is not definitely stated until 1880, when it was added to the list of gold-producing regions, with an output of $6,000, which since that time has increased many times over, but not steadily, until in 1903 it amounted to $8,614,700." In 1907 it amounted to $19,349,743.

"The first gold was discovered on the islands of the Alexander Archipelago and along the adjoining coast, but subsequently prospectors found their way into the interior, the first strikes there being made in British Columbia near the head of the Stikine River. These were fol-

lowed by discoveries in the Yukon Valley, especially along some of the tributaries known as Birch Creek, Mission Creek and Forty Mile Creek. In 1896 still richer discoveries were made along the Klondike River, and within a year the yield of this region had exceeded the purchase price of Alaska. Other discoveries have since followed rapidly.

"The gold deposits of Alaska are of two types, viz., quartz veins and placers. The former are prominent along the coast, and the most important producer is the Treadwell group of mines on Douglas Island, southeast of Juneau. The geology of this region bears in many ways a strong resemblance to the California gold belt, and is probably of similar age. The section involves a series of steeply dipping slates and greenstone and diorite dikes. The ore bodies are dikes of albite-diorite, permeated with metallic sulphides and carrying small amounts of gold, with a hanging wall of greenstone and a foot wall of black slate. The veinlets which are thought to have been formed by shearing stresses incident to epeirogenic movements, occur in two sets of fractures at right angles to each other. Spencer believes that the mineralization has been caused by hot ascending solutions of possibly magmatic origin. Secondary concentration is not in evidence, and it is thought that the depth to which the ores can be worked will depend more on the increased cost of mining at great depths rather than on exhaustion of the ore. At present an almost continuous ore-body has been developed for 3,500 feet.

"The placer deposits have been found in many parts of Alaska, but the two regions which have yielded the largest amount are the Yukon region and the Seward Peninsula, the latter being now the first.

"Gold was discovered in the Forty Mile District of the Yukon in 1886, and caused a stampede for this region; but the deposits of the Klondike did not become known until 1896, and their discovery was followed by a rush of gold seekers that eclipsed all previous ones. Indeed, it is said that by 1898 over 40,000 people were camped out in the vicinity of the present site of Dawson.

"The Klondike region proper is situated on the eastern side of the Yukon River, and the richer deposits found

have been on the Canadian side of the boundary. The gold has collected either at the bottom of the gravel in the smaller streams tributary to the Yukon, or else in gravels on the valley sides, this latter occurrence being known as bench gravel. The metal is supposed to have been derived from the quartz veins found in the Birch Creek, Forty Mile and Rampart series of metamorphic rocks lying to the east. . . . The annual output has decreased, and mining in the Klondike region has settled down to a more permanent basis. Gravels running under $9 per cubic yard cannot be worked at a profit, because the difficulties and expenses of running in such a region are great, and form an interesting comparison with conditions in California, where gravel carrying 25 cents per yard is considered good, while that running as low as 5 cents per yard can be worked.

"Since the discovery of the rich gold gravels on the Yukon, auriferous gravels have been developed in many other parts of Alaska, where they are being more or less actively worked, but of these various finds those in the Seward Peninsula, which is now the largest producer, have been the most important.

"The first of the localities discovered in the last-mentioned region was Cape Nome, which for a time proved to be a second Klondike. The gold was discovered here on Anvil Creek, and the following year in the beach sands where Nome now stands.

"These discoveries caused another northward stampede, which resulted in the rapid exhaustion of the beach sands; but other deposits were found farther inland near Nome, as well as the other localities on the Seward Peninsula. Some quartz veins are also worked. Ophir Creek is now the largest producer on the Seward Peninsula."

According to the "Mineral Resources of the United States," for 1907, the production of gold, silver and copper in Alaska in 1907, by districts, is as follows:

District.	Gold.		Silver.		Copper.	
	Quantity Fine Ounces.	Value.	Quantity Fine Ounces.	Value.	Quantity Pounds.	Value.
Pacific Coast Belt, including southeastern Alaska and Prince William Sound	139,886.06	$2,891,743	74,415	$49,114	6,308,786	$1,261,757
Copper River and Cook Inlet	13,303.13	275,000	1,785	1,178		
Yukon Basin	444,227.65	9,183,000	48,087	31,738		
Seward Peninsula	338,625.00	7,000,000	25,497	16,828		
Total	936,043.84	$19,349,743	149,784	$98,858	6,308,786	$1,261,757

References for Alaska Gold Region.

1. "Economic Geology of the United States," by Heinrich Ries.
2. Bull. 213, U. S. G. S., pp. 41, 49, 71.
3. Bull. 225, U. S. G. S., pp. 60, 64, 74, 28, 43.
4. *Min. Mag.*, Sept., 1904, p. 203. (Map showing mineral wealth of Alaska.)
5. *Eng. and Mg. Jour.*, Oct. 20, 1906, pp. 719–723. (Frozen gravels and methods of treating.)
6. A. I. M. E., Sept., 1904, by A. H. Brooks.
7. Professional Paper No. 20, U. S. G. S., by F. C. Schrader.
8. Professional Paper No. 1, U. S. G. S., by A. H. Brooks.
9. *Nat. Geog. Mag.*, Jan., 1900, pp. 15–23.
10. Professional Paper No. 15, U. S. G. S., by Mendenhall and Schrader.
11. I. M. M. E., Vol. 8, pp. 519–534, by J. B. Tyrrell.

SUPPLEMENTARY NOTES.

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Tonopah Mining District, Nevada.—The following is taken chiefly from Professional Paper, No. 42, of the U. S. G. S., by J. E. Spurr. Tonopah is situated in Nye County, Nevada, near the Esmeralda County line. It lies south of Belmont and about sixty miles east of Sodaville, on the Carson and Colorado Railway. It is situated in the western part of what has been called the Great Basin Region. In this region parallel north-south mountain ranges and low, irregular hills and mesas, having also in general a north-south alignment, alternate with broad, flat or gently sloping valleys. The valleys and low hills are bare, due to the aridity of the climate, save a few scattering sagebrush. The topography is typical of volcanic areas. Numerous isolated or connected irregular hills—denuded volcanic necks—rise from a rolling plane. The camp is a comparatively new one, the first discovery being made by a resident of Belmont in 1900. This party collected samples of white quartz from the outcrops of Mizpah Hill which ran from $50 to $600 per ton in silver and gold. The first two tons of ore shipped netted $600. In the winter of 1902–3 rich ores were discovered at a depth of several hundred feet in the ground of the Montana Tonopah shaft which had been sunk through barren andesite. Later on other shafts also encountered ore at a considerable depth, *e. g.*, the North Star, the Desert Queen and the Tonopah Extension. These, however, were all near the original finds, very little ore being found in the outlying territory.

Geology.—In the immediate vicinity of Tonopah the rocks are all Tertiary volcanics or tuffs. Limestone, however, occurs eight or nine miles south of the camp and limestones and granites occur also several miles north of Tonopah and at intervals between Tonopah and Belmont. The succession of volcanics represented in the Tonopah Mining District is as follows:

1. *Latest Rhyolite or Dacite.*—A black, very glassy, thin flow overlying a coarse, stratified tuff made up of fragments of glass.
2. *Brougher Dacite.*—Forms most of the important hills which are the necks of volcanoes. Occurs as black glass, volcanic agglomerate, etc., and often shows powerful flow lines.
3. *Oddie Rhyolite.*—Frequently glassy, sometimes pro-

foundly brecciated and contains large cavities filled largely with calcite.

4. *Basalt.*—Occurs in only one small area near the top of Siebert Mountain. Chiefly a flow of vesicular basalt 40 or 50 feet thick extending south off the area of the map.

5. *Siebert Tuffs (Lake Beds).*—Forms a conspicuous feature of the geology near Tonopah. Usually beautifully and uniformly bedded. Do not vary in character for thicknesses of several hundred feet.

6. *Tonopah Rhyolite-dacite.*—Varies in color through gray, bright red, black and white, often showing fine brecciation. Often glassy and dense, especially near contacts of intrusive masses or in the thin sheets.

7. *Fraction Dacite Breccia.*—Sometimes non-fragmental and of the nature of a flow. Invariably soft and friable. Often consist of broken, close-packed, medium-sized fragments of more or less pumiceous dacite. Largely the result of explosive volcanic action.

8. *Heller Dacite.*—Characterized by its abundant glassy ground mass, and abundant inclusions of water-worn pebbles, granite and later andesite.

9. *Later Andesite.*—Much like earlier andesite but less siliceous. Has medium dark color, mottled with crystals of feldspar and biotite. Sometimes purplish. Sometimes thoroughly altered to calcite, chlorite, serpentine, quartz, siderite and pyrite.

10. *Earlier Andesite.*—Oldest of Tertiary volcanics. Commonly called lode porphyry. Never fresh but always decomposed. Freshest specimens are light-colored, dense, finely-porphyritic rock with small glistening feldspar phenocrysts showing on fresh fracture. They have a green tinge due to chlorite at depth and a yellow tinge from iron oxide near the surface.

Faulting.—The southern half of the district has suffered a great amount of faulting as a glance at the map clearly shows. Many of these faults were first observed through certain peculiar topographical features. *E. g.*, parallel valleys and ridges marked the positions of fault blocks, the valleys marking the positions of the more easily eroded formations and the ridges the positions of the more resistant ones. They were also shown by clear-cut fault scarps, many of which had a zigzag form due to the intersection of two systems of faults. Faults were also often indi-

cated by rectilinear boundaries to certain formations. This is not an absolutely sure sign of faulting, especially if one of the formations is intrusive. For example, the contact of the Golden Mountain dacite with the earlier andesite on the east side of Gold Hill is so straight as to suggest faulting. Also south of Gold Hill the long south contact of the same intrusion forms alternating straight northwest-southeast and northeast-southwest courses, strongly suggesting the intersection of two intersecting systems of faults. But excellent evidence that the contact has not been faulted is present in the band of dacite glass which represents the quickly chilled lava along the margin of the intrusion and which was found to follow the contact along its different courses. Many of the faults located on the surface were subsequently found in the mine workings. As illustrations are the Mizpah, Burro, Wandering Boy and Fraction faults.

Cause of Faulting.—The Brougher dacite which is confined to the southern half of the area mapped is coextensive with the region of observed complicated faulting, suggesting a connection between the dacite intrusion and the faulting. The faulting occurred subsequent to the eruption of all the rocks older than the dacite but the dacite is never faulted. The complexly faulted southern half of the area is down-sunken in comparison with the little faulted northern half. Near the dacite necks the faults are more numerous than elsewhere, and in many instances the blocks adjacent to the dacite have been down-sunken in reference to blocks further away. From these intrusive necks the faults run in a roughly radiating fashion and seem to follow no regular system of trend. Detailed study of the contact phenomena of the dacite shows that the minute faults in the tuffs at these points generally have their downthrow sides next to the dacite. From these facts the following conclusions have been reached. The faulting was chiefly initiated by the intrusion of the massive dacite necks. After this intrusion, and subsequent eruption, there was a collapse and sinking at the vents. As the still liquid lava sank it dragged downward the adjacent blocks of the intruded rock accentuating the faults and causing the phenomena of downfaulting in the vicinity of the dacite.

Earlier Andesite Veins.—The most important veins of the Tonopah District occur in the earlier andesite and do not

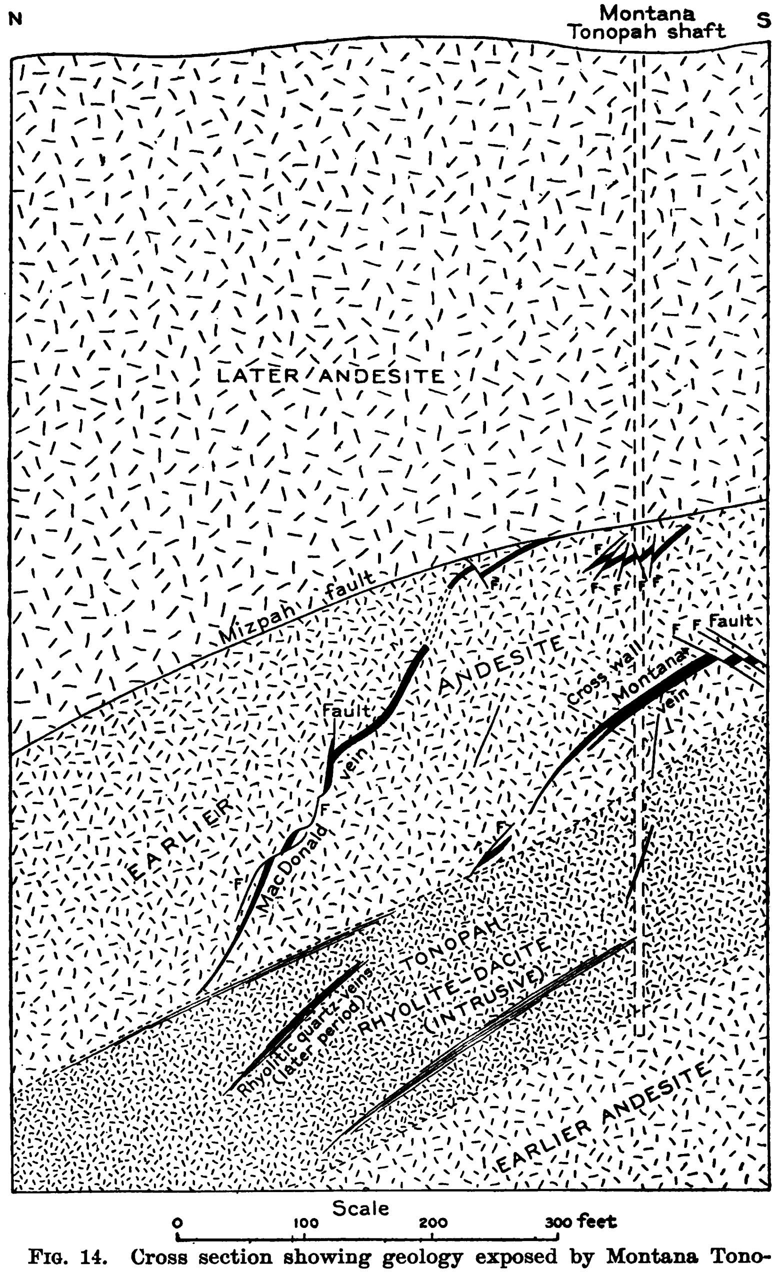

FIG. 14. Cross section showing geology exposed by Montana Tonopah workings. (From U. S. Geological Survey, Professional Paper, No. 42, p. 176, Fig. 66.)

extend into the overlying rocks; hence, where the earlier andesite is not exposed at the surface the later rocks form a capping to the veins. This fact shows plainly that the veins were deposited before the eruption of the later andesite and immediately after that of the earlier andesite, for the period of erosion between the two andesites seems to have exposed the veins at the surface, indicating that they were formed before this period or early in it. Fig. 14 shows mineralized earlier andesite with the veins terminating at the contact with later andesite and also at the contact with Tonopah rhyolite-dacite. The openings which afforded channels for water circulation were in the nature of sheeted zones. The rock was complexly fractured, apparently soon after cooling, and probably as a result of the stresses exerted by the still active volcanic energy below. A major set of fractures extended in an east and west direction and zones of cross-set parallel fractures attain a maximum thickness of several feet. In places, the circulating waters diverged into separate channels, which diverged and frequently reunited. The circulation channel now occupied by the Mizpah vein may be taken as a type of the main fracture zones, and the diverging Burro veins, dwindling as they increase their distance from the master veins, represent the lateral channels. The slitting and reuniting is shown by the structure of the veins at many points. That the circulation channel was in practically every case a fracture zone and not an open fissure is shown by the fact that there exist all stages in the change from a fracture zone in country rock to a solid quartz vein. In many cases the vein consists simply of a zone of more or less altered andesite, not essentially different, except, perhaps, for a somewhat greater silicification, from the andesite which forms the walls. This zone is cut by parallel fractures having the same strike and dip as the walls, and the walls themselves are nothing more than stronger fractures of the same kind. In the next stage, where part of this fractured zone becomes altered to quartz, the main wall fractures have been the most favorable for water circulation, so that sometimes a hanging-wall streak of quartz and a foot-wall streak are found with only altered andesite between. Next, streaks of quartz parallel with the walls may be found, or the quartz may form a network in the andesite. Thus the process may be traced to the stage where the whole

of the andesite is replaced by quartz, forming a solid vein several feet in width. As a rule, however, more or less decomposed andesite forms part of the vein. As exceptions there are found streaks of quartz, usually small, within the vein, which show crustification and comb structure and thus bear evidence of having been formed in cavities. These cavities, however, are usually irregular in shape and are spaces of dissolution and were the effect of mineralizing waters themselves. Cavities two to three feet in diameter occur in the Montana Tonopah workings and represent about the maximum size. Especially rich deposits often occur at the intersection of transverse fractures with the main ones.

Tonopah Rhyolite Dacite Veins.—In many mine workings there are quartz veins, which are large and may carry values, which cut the Tonopah rhyolite-dacite. These are easily confounded with the veins of the earlier andesite, just as the silicified Tonopah rhyolite-dacite, in which they usually occur, may be confounded with highly silicified phases of the earlier andesite. Such veins have been encountered in the Belle of Tonopah, the King Tonopah, the Mizpah Extension, Ohio Tonopah, the Desert Queen, North Star, Montana Tonopah, Miszpah, Midway, MacNamara, West End and Tonopah Extension. Their resemblance to the andesite veins has caused a great deal of exploration which, on the average, has been decidedly unprofitable. These veins are characterized by irregularity and by lack of definiteness and persistence. The quartz they contain is usually dense and jaspery and is white, gray or black as distinguished from the white quartz of the earlier andesite veins. The veins are usually barren or contain only very small quantities of gold and silver.

The ratio in value of gold to silver is usually higher in these veins than in the earlier andesite veins where the ratio is about as 2 to 3. These Tonopah rhyolite dacite veins are younger than the Tonopah rhyolite dacite. The period of mineralization was, in broad terms, contemporaneous with the volcanic activity of the Tonopah rhyolite dacite period and very likely persisted for some time afterward. They are plainly the results of ascending hot waters and, as in the case of the Tonopah Extension, the earlier andesite veins have sometimes been reopened and the opening filled with a new vein of barren jaspery quartz.

Primary Ores.—The Montana Tonopah veins carry solid sulphide ores, primary and contemporaneous with the original quartz gangue and very slightly altered, presenting strong contrast with the oxidized ores of the Mizpah Mine. Similar sulphide ores have been found in the North Star, the Tonopah Extension, the Midway and the Tonopah and California. In these veins the chief gangue mineral is quartz rather fine-grained and dense and mixed with some aluminous material which the microscope shows to be sericite. The quartz holds numerous fluid inclusions which contain bubbles, showing that the included material was in a state of vaporous tension at the time of the vein formation and that it is contracted so as to fill only a part of its original chamber upon the lowering of the temperature. The principal metallic mineral of the ores is a black sulphide, usually dense, fine-grained, and intimately intermingled with the quartz. It is seldom crystallized. A partial analysis showed appreciable amounts of antimony and copper, indicating that the mineral is polybasite rather than stephanite. Silver chloride is found in some of the primary ores, interwoven with the primary sulphide in such a way as to denote contemporaneous crystallization. Chalcopyrite in occasional small grains is often seen in the primary ores. Pyrite is comparatively rare, but when present is often interwoven with the primary silver sulphide. Galena occurs in the high-grade sulphide ores of the Montana Tonopah associated with silver sulphide, chalcopyrite and pyrite. Gold has never been detected by the eye in the sulphide ores, though it has been found in metallic particles in the oxidized ores.

Depth of Oxidation.—This depth is exceedingly irregular, being quite different in neighboring shafts. The difference plainly depends on the porosity and fracturing of the rocks. The veins which outcrop are most deeply oxidized, as the Mizpah and Valley View veins. The former is oxidized to a depth of 700 feet; the latter to a depth of 500 feet. Where veins do not outcrop, but are covered by a blanket of overlying rock, there is usually very little oxidation. For example, the ore in the Fraction at a depth of 200 feet is sulphide ore.

Origin of the Tonopah Ores.—Regarding the genesis of the ores I quote directly from J. E. Spurr, the author of Professional Paper 42. "The Tonopah District was, during most of Tertiary time, a region of active volcanism, and

probably after each eruption, certainly after some of them, solfataric action and fumarolic action, succeeded by hot springs, thoroughly altered the rocks in many parts of the district. At the surface, during those periods, the phenomena of fumarolic and solfataric action and of hot springs were similar to those today witnessed in volcanic regions; but the rocks now exposed were at that time below the surface. The veins fill conduits which were formed by the fractures due to the heavings of the surging volcanic forces below and along which the gases, steam, and finally hot waters, growing gradually cooler, were forced, relieving the explosive energies of the subsiding volcanism. The water and other vapors, largely given off by the congealing lava below, carried with them, separated and concentrated from the magma, metals of such kind and of such quantities as are present in the veins, together with silica and other materials. The nature of the metallic minerals in the veins in this case is believed to depend largely upon the particular magma whence the emanations proceeded. In the chief Tonopah veins this was the earlier andesite. Other factors, such as relative depth, have evidently an important controlling influence."

References for the Tonopah District.

1. Professional Paper No. 42, U. S. G. S., by J. E. Spurr.
2. Bull. 213, U. S. G. S., p. 81, by J. E. Spurr.
3. Bull. 260, U. S. G. S., pp. 132, 140, by J. E. Spurr.
4. Bull. 225, U. S. G. S., p. 89, by J. E. Spurr.
5. *Mng. World*, Nov. 26, 1904.
6. *Eng. and Mg. Jour.*, Vol. 76, pp. 769–770, by J. E. Spurr.
7. *Franklin Inst. Jour.*, Vol. 160, pp. 1–20, by J. E. Spurr.

The Goldfield District, Nevada.—The following notes are taken chiefly from Bull. 260, U. S. G. S., by J. E. Spurr. This district is situated twenty-three and one half miles south of Tonopah and was located late in the spring of 1903. About January and February, 1904, rich finds were made in certain places south of Columbia Mountain. It is estimated that $2,000,000 worth of ore had been shipped up to November, 1904.

General Geological Situation.—"The district is bounded on the west by a lava-capped mesa whose erosion has laid bare the underlying gold-bearing rocks. The gold-bearing region is characterized by numerous low irregular ridges standing out from the lower and more nearly level surface.

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

These ridges owe their origin to hard reefs of quartz which form their crests, whose resistance to erosion has left them thus protruding above the general elevation; and in these quartz reefs the auriferous deposits are found.'' The most prominent of the ridges is known as Columbia Mountain. The most productive area is enclosed in a square two or two and one-half miles in either direction.

Nature of Ore Deposits.—The veins at Goldfield are neither persistent nor well-defined. The outcrops of the quartz bodies are irregular, straggling, branching, and apt to disappear suddenly. The quartz itself is gray and jaspery and is due almost entirely to the silicification of the volcanic rock in which it occurs. The greater part of these jasper quartz reefs, although showing disseminated pyrite, contains little or no values in gold. Prospecting, however, has led to the discovery of portions containing gold, sometimes in large quantity. This mass is surrounded by a barren siliceous portion. While the siliceous casing may be 25 or 30 feet wide, the auriferous portion may be only a foot or two wide. These pay shoots probably represent the main channels of hot water circulation. The ores are often of very high grade. As an extreme example may be noted a shipment of fourteen and one half tons from the Sandstorm mine, which yielded $45,783 when worked in a stamp mill, while the tailings still contained about $1,000 to the ton. From the McKane-Bowes lease on the Jumbo there was taken out in five months from a space 100 feet long and 220 feet deep on the shoot, $600,000. One small shipment from the lease—917 pounds of ore—yielded $4,766. The whole production of the camp has been from ore which, roughly estimated, averaged $200 to $300 per ton. Most of the ore extracted up to the present time has been oxidized ore. The ores are mixed sulphides and oxides up to near the surface. The oxidized material which follows cracks and seams is sometimes found to be several hundred times as rich as the unoxidized portion. The irregular spongy nature of the free gold particles is the proof that this is gold that has been dissolved and redeposited in concentrated form during the process of oxidation. The ground water level is from 150 to 200 feet in depth, showing that the oxidized ore is only a temporary supply. Rich sulphides, however,

occur below this level. A sulphide, probably tetrahedrite, contains tellurium, indicating that the sulphide ores may also be very rich.

Period of Mineralization.—Regarding the period of mineralization, J. E. Spurr says: "At Goldfield the ores occur in both rhyolite and andesite showing that mineralization followed the eruption of both lavas. At Gold Mountain the ores evidently were formed after the eruption of the rhyolite, and at Tonopah the eruption of the earlier (dacitic) rhyolite was followed by a period of mineralization which produced veins showing, frequently, a larger proportion of gold than the locally more important veins whose formation followed the eruption of the earlier andesite. There is, therefore, the possibility that the Goldfield deposits are identical in origin with the later series of veins at Tonopah."

REFERENCES FOR THE GOLDFIELD DISTRICT.

1. Bull. 260 U. S. G. S., pp. 132–139, by J. E. Spurr.
2. *Eng. and Mg. Jour.*, Vol. 78, pp. 383–384, by M. D. Draper.
3. *Am. Geol.*, Vol. 35, pp. 382–385, 1905, by H. V. Winchell.
4. Bull. 225, U. S. G. S., p. 118, by J. E. Spurr
5. *Eng. Mg. Jour.*, Vol. 81, p. 843.

The Tintic District.—The notes on the Tintic district are taken chiefly from Folio No. 65, U. S. G. S., by G. W. Tower, G. O. Smith and S. F. Emmons. This district is something over seventeen miles long north and south by about thirteen miles east and west and includes portions of Juab and Utah Counties, Utah. The district includes the central portion of the Tintic Mountains with parts of adjacent valleys. These mountains form in this latitude the easternmost of the narrow mountain ranges which rise abruptly from the level valleys of the Great Basin, and they have the north and south trend characteristic of this type of mountains. In the northern portion of the district the Tintic Mountains form a well-defined, narrow, and simple mountain ridge, bordered by wide valleys to the east and west. In the southern portion of the district important transverse spurs extend eastward beyond its boundaries and almost connect this range with the Wasatch. At the northern end of the range similar low spurs extend to the west. Within the limits of the district the crests of these mountains attain an altitude of over 8,000 feet, Tintic Mountain being 8,214 feet. In

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

the northern portion the more important peaks are Packard and Eureka peaks, Godiva Mountain, Mammoth and Sioux peaks and Treasure Hill. Tintic valley bordering the range on the west has an elevation of 5,600 feet, and Goshen valley, on the east, is 4,500 feet above sea level. The relief is marked, and the abruptness of the change from the steep mountain slopes to the almost level valley floors is a striking feature. The Tintic Mountains in fact represent only the upper parts of a mountain mass, the lower slopes and foothills of which are concealed beneath the valley bottoms.

In 1905 this district ranked as the greatest producer of precious metals in Utah. It is also one of the oldest mining districts in that state. The mines have been worked continuously for the last forty years and have added many millions of dollars to the world's supply of precious metals, as well as much lead and copper contained in the ores. The production of gold, silver and associated metals with corresponding values in 1905 from the Tintic district is as follows: Gold—100,942 fine ounces; value $2,086,656. Silver—3,951,348 fine ounces; value $2,386,-614. Copper—10,982,751 pounds; value $1,713,309. Lead—18,702,573 pounds; value $879,021. Other metals; value $60,051. Total value of metals from the district in 1905, $7,125,651. The geological succession for the district is as follows:

Pleistocene	1. Alluvium. (Stream gravels, sand and silt.) 2. Bonneville Lake Beds. (Sand, and gravels in terraces, bars and deltas.)
Neocene	1. Monzonite. (Porphyritic in part.) 2. Andesite. (Lava flows and tuffs, latite in part.) 3. Packard Rhyolite. (Flows and sheets.) 4. Pernow Rhyolite. (Lava flows.) 5. Swansea Rhyolite. (Mainly intrusive.)
Carboniferous	1. Humbug Formation. (Alternating beds of fossiliferous sandstone and limestone. 250 ft.) 2. Godiva Limestone. (Blue and black fossiliferous limestone. 2,200 ft.) 3. Mammoth Limestone. (Gray and blue dolomite and dolomitic limestone. 4,000 ft.)
Cambrian	1. Tintic Quartzite. Massive quartzite with clay slate at top. 7,000 ft. exposed.

Fracture Systems.—"The fracture systems of the district may be divided into two distinct classes; the first and more important are those which occur in sedimentary rocks; the second are confined to the igneous rocks. Fracturing and mineralization in the sedimentary rocks occurred before the volcanic activity and therefore previous to fracturing and mineralization in the igneous rocks." Fractures are abundant in sedimentary rocks and are most readily traceable in the quartzites and harder limestones. They are most abundant in the vicinity of the three great mineral-bearing zones; the Eureka zone, the Mammoth zone and the Godiva-Sioux Mountain zone. The great majority of fractures occur in the northeast and southwest quadrants, but the most persistent are within a few degrees of north-south. Northwest and southeast fractures are less abundant. The fracture planes are nearly vertical, but in a few cases dip east or west at an angle that is rather less than 70 degrees. Certain east-west fractures occur and crossing the stratification are more easily recognized. They are apparently later than the other fractures. The Spy-Ajax fault, which crosses the Mammoth Gulch to the Northern Spy Mine is the most prominent east-west fracture. The majority of the fractures cross, but appear not to have faulted one another. An exception is the Spy-Ajax fault which displaces north-south fractures. The north-south fractures, which are by far the most common, are also most abundant on the west limb of the synclinal trough which crosses the district from north to south. On the east limb where the strata dip at low angles north-south fractures are not common.

Eureka Fracture Zone.—This zone extends from the Gemini Mine, northwest of the town of Eureka, through the Bullion-Beck, Eureka Hill, and Centennial-Eureka Mines, to the Southern Eureka, Tennessee Rebel and Opex Mines in Mammoth Basin. The greatest fracturing has been between the Bullion-Beck and Eureka Hill shafts. Directions of fracturing vary, but the most common are north-south and the ore-bodies follow the fracture planes in their varying directions. Few later or secondary fractures were observed in this zone.

Mammoth Zone.—This zone commences on the north at the Eagle Mine and extends southward through the Grand Central, Mammoth, Ajax and Lower Mammoth mines.

The most prominent and most numerous fractures have a general north-south direction. N. 25° E. and N. E. fractures are also very common. The Spy-Ajax fault which crosses this zone from east to west has displaced the strata on the south side and carried them 1,000 feet to the eastward. At the southern end of the Mammoth Mine, at the intersection of several fissures the ore forms a large elliptical shaped chimney which has been traced continuously for more than 1,600 feet in depth. In the Grand Central Mine the ore-body follows north-south fractures in part, but the main axis is N. 30° W. or nearly parallel with the strike of the strata. In the Eagle Mine the ore-body trends a few degrees west of north and has a vertical dip.

Godiva-Sioux Mountain Zone.—This begins on the south at the North Star, extends northeast to the east side of Sioux Mountain, thence northward to Godiva Mountain. The principal fracture directions in the south and central portions are from N.-S. to N. 35° E. In the northern part N.-S. and N. 15° to 30° W. fractures prevail. The fractures are all vertical. The ore-bodies follow the fractures. At the south end the ore zone consists of several short ore-bodies while in the central portion there is a single ore-body which has been followed continuously from the Clarissa to the Utah Mine, a distance of 5,000 feet. Beyond this to the north the bodies are less regular, being short and lense shaped. In the Northern Spy, Sioux and Utah mines, in the central portion the ore-bodies, which are vertical, or have a steep western dip in the lower levels, are inclined to depart from the fractures at the contact of the Godiva and Humbug formations and follow the bedding planes of the strata.

Fractures in Igneous Rocks.—The fractures in the igneous rocks occur mostly in the more solid types, the monzonite and quartz porphyry. Fissures trending N. 15° and N. 35° E. are the most abundant. They are always nearly vertical, the dip rarely being less than 80 degrees and often changes from east to west within 100 feet. They all die out near the sedimentary rocks. Secondary fractures are very rare, the only ones noted being two in the Swansea Mines, which displace the mineral-bearing veins about 10 feet.

Ore Deposition.—The ore deposits of the region occur along fracture zones within the sedimentary and igneous

rocks and at the contact between the two. Those of the sedimentary rocks are almost entirely confined to the three fracture zones above mentioned. In the igneous rocks the deposits consist of a number of short, widely interspaced veins. The Tintic iron mine, on the northern side of Dragon Gulch, has the most considerable contact deposit. The more common minerals of these deposits are pyrite, galena, sphalerite, and enargite and their oxidation products carrying silver and gold with quartz and barite as gangue minerals. The ores in the sedimentary rocks are oxidized to a depth of at least 1,600 feet in the sedimentary rocks. In the igneous rocks the level of ground water varies from 200 to 700 feet in depth. The ore deposits are completely oxidized above the level of ground water, but quite free from oxidation below it.

At the north end of the various ore zones lead and silver predominate almost to the exclusion of copper and gold as is shown at the Gemini and Godiva mines, while the Centennial, Eureka and North Star at the south end produce more copper and gold than lead and silver. Gold, which is found almost exclusively in the deposits in the sedimentary rocks, is rarely detected by panning, and hence probably occurs in some chemical combination. Silver yields the principal values in all the deposits. It occurs in the form of cerargyrite or argentite in the igneous rocks, and as cerargyrite in the sedimentary rocks. Lead occurs in both sedimentary and igneous rocks and copper principally in the sedimentaries. The iron of the contact deposits is valuable, being used for fluxing purposes. Galena and pyrite are the most abundant metallic sulphides, and enargite is the principal form of copper as originally deposited. By the oxidation of the deposits in the sedimentary rocks the metals have been separated into ore-bodies in which one or the other predominates. *E. g.*, in the Eureka Hill, Mammoth, Ajax, Clarissa and Northern Spy Mines large bodies of oxidized copper ore have been found which carried practically no lead values. Equally large bodies, almost exclusively of lead ore, occur in the Eureka Hill, Bullion-Beck, Utah, Sioux and Mammoth mines, while large amounts of cerargyrite were taken from the Gemini Mine. Contact deposits usually occur at the contact of igneous rocks with limestone. Mineralization has formed great

masses of siliceous material impregnated with hematite and limonite and containing locally small amounts of precious metals. The iron ore of the Tintic Iron Mine contains about 80 per cent. of iron oxide, 14 per cent. of water and 3 per cent. of silica.

Cave Deposits.—Cave deposits constitute an unusually interesting and important feature of the Tintic ore-bodies in limestone. The great elevation of the limestone above the bottom of the surrounding valleys afforded a great depth of run-off to surface waters, and hence favored the formation of caves in the limestone. A large number of the existing open caves occur over oxidized ore-bodies and evidently owe their existance to the settling to the bottom of the material of a large ore-body. In the oxidation of the bodies of sulphides which replaced the limestone there was a removal of a certain proportion of the constituents. That left the mass in a porous condition, somewhat in the nature of a loose aggregation of sand grains. A subsequent shaking up of the mountain mass caused the loose material to settle to the bottom and left an open space above. In the cave in the 1,300 foot level of the mammoth mine, for example, portions of the ore are still seen clinging to the roof of the cave.

Relative Age of Veins in the Sedimentary and Igneous Rocks.—Regarding this subject Mr. S. F. Emmons says: "It seems well established by the evidence obtained in the field that the original deposition in the sedimentary rocks occurred previous to the eruption of the igneous rocks, but in the usually oxidized condition of these deposits one cannot be sure that additional mineralization has not subsequently taken place in the sedimentary rocks, and possibly at the time of ore deposition in igneous rocks. There has undoubtedly been a later shattering or fissuring of the sedimentary rocks since the formation of the original fissures, and it may reasonably be assumed that this took place at the time of the formation of the fissures in the igneous rocks that have since become mineral-bearing veins. . . . The original fissuring of the sedimentary rocks is assumed to be mainly of later date than the folding, for the reason that a great number of the fractures cross the bedding at a low angle either in strike or in dip. . . . If the assumption is correct that the fissuring in the igneous rocks was accompanied by a renewal of movement

in the fracture zones of the sedimentary rocks, it is probable that the fissures in the latter now extend to a considerable depth, and are not likely to decrease in value with depth; except possibly a change from enriched oxides to sulphides and arsenides, until the fractures have passed into the underlying quartzite at the bottom of the supposed synclinal basin."

References for the Tintic District.

1. Tintic Special Folio U. S. G. S., No. 65, by G. W. Tower, G. O. Smith and S. F. Emmons.
2. 19th Ann. Rept. U. S. G. S., Pt. III, p. 601.

PLACERS.

Under this head is included the more resistant products of weathering, such as native gold and quartz, which have been washed down from the hills on whose slopes the gold-bearing quartz veins outcrop. These materials being too coarse or too heavy to be carried any great distance, naturally settle down in the stream channels, and the gold being of higher specific gravity collects in the lower part of the gravel deposit. Other substances may, and often do, accompany the gold, such as native silver, platinum, magnetic sands, tin, garnet, zircon, monazite, columbite, iridosmine, Josephinite, etc. The nature of the deposit in the original vein of course determines the nature of the substances in the gravel deposits.

Certain of the above minerals, *e. g.*, tin and monazite are characteristically associated with acid igneous rocks such as granites, gneisses, pegmatites, etc., while others such as platinum and magnetite are more frequently associated with the more basic rocks. The finer constituents associated with gold have received the names "yellow sands" and "black sands" depending upon the relative abundances of such substances as zircon, monazite, garnet, magnetite, etc.

For example, where native gold occurred in large masses in the original veins nuggets of great size are sometimes found in the auriferous gravels derived from them, such, for example, as the two large nuggets recorded from Victoria. One, the "Welcome Stranger" weighing 2,280 ounces and the other, the "Welcome

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

Nugget'' weighing 2,166 ounces. On the other hand, where the gold occurs in the original vein in very finely divided form, as, for example, in some of the veins of Tertiary age in the Cordilleran region, the conditions for its preservation in the form of placer deposits are not so favorable.

Deposits resulting from the action of running water and from atmospheric weathering are so varied in their nature that it becomes necessary to consider these deposits of auriferous gravel from the standpoint of origin. They will therefore be discussed under the following heads.

1. **Creek Placers.**—These may occur in, adjacent to, or at the level of small streams. Such gravelly deposits may be washed down from the surrounding slopes and gradually accumulate in the bottom of the valley. The softer portions of the disintegrated materal are ground up and borne away in suspension, the soluble constituents are taken into solution, but the insoluble and more resistant materials gradually accumulate, frequently into auriferous gravels.

2. **Hillside Placers.**—These are placers which accumulate on the slopes and are intermediate between Creek and Bench deposits. They are probably due in part to running water often descending from regions of perpetual snow and in part to atmospheric disintegration. The rock including the auriferous quartz veins become disintegrated and the resistant materials accumulate, often near the foot of the slope.

3. **Bench Placers.**—These are placers in ancient stream deposits often several hundred feet above the present streams. Often after a stream has established its course and built up its flood plain to a certain extent, crustal deformation gives the stream a steeper grade and in consequence it cuts its way down through its original flood plain, leaving that to project from the valley slopes in the form of benches or terraces. Again, either due to the extrusion of sheets of molten rock or to subsidence and sedimentation, ancient stream deposits are buried. Later when new drainage channels are established these old previously buried ancient stream deposits are exposed far above the beds of the newly formed stream.

4. **River Bar Placers.**—These are placers which occur on

gravel flats in, or adjacent to, the beds of large streams. Such placer deposits may accumulate in the bed of a stream where a resistant rock formation or any other obstruction deflects the current. In such a case the velocity of the current is often reduced and the heavier material is dropped and finally forms a bar. Such gravel deposits are familiar features along any of our small streams after times of high water. The formation of such bars causes the stream to change its course and in time the deposits laid down in the form of bars often become an important source for auriferous gravels. Where two confluent streams unite they often form bars composed of auriferous gravels and knowing the presence or absence of such deposits above the point of union greatly assists in tracing out the origin of the gravel.

5. Gravel Plain Placers.—This type of placer deposit is sometimes formed where swift flowing mountain streams issue upon the surrounding level flats. The velocity of the current is decreased and the load is dropped in the form of alluvial cones and fans. These uniting form wide stretches of alluvial material at the foot of the steeper slopes which are known as piedmont alluvial plains.

6. Sea Beach Placers.—These are placers adjacent to the sea shore to which the waves have access. Such placers occur along the coast of California and Oregon and around Nome. In certain places long stretches of the high bluff along shore are gold-bearing with rich and poor streaks. Also older beaches containing the black sands exist as much as thirty miles inland from the present shore and at considerable elevation. These gold-bearing sands and gravels were probably deposited by ancient rivers which flowed through the gold regions of Oregon and California. The auriferous sands occurring along the beaches of Oregon, and Nome, are probably due in part to the discharge of rivers into the ocean and in part to the wearing down of the auriferous shore formations. The sands contain gold and platinum in small quantities, in minute scales, most of which are flat, mixed with a very large percentage of black, magnetic, and ordinary beach sand.

7. Lake Bed Placers.—These are placers which accumulated in the beds of present or ancient lakes; sometimes formed by landslides or glacial damming or by material

SUPPLEMENTARY NOTES.

SUPPLEMENTARY NOTES.

brought down from the surrounding country by streams and deposited. The mining of the rarer metals from placers is largely confined in this country to California and Alaska. Gold dredging has developed into a most important industry in California. The value of the gold obtained by this method in 1907 amounted to over five seventh of the entire production from placers. Fifty-seven dredges were operating in California but only four were operated in Alaska. Drift mining in frozen ground has yielded most of the gold from the lower Tanana in Alaska, and a large part of the gold from Seward Peninsula is also obtained by this method of mining.

CHAPTER IX.

COAL, OIL AND GAS.

COAL.

The intimate gradation between vegetable accumulation now in the process of formation and mineral coal prove almost without doubt that coal is of vegetable origin. By a series of slow changes the vegetable remains lose gases and water, the carbon becomes concentrated, and the materials take on the appearance of coal. To the stages of this process names are given, four of which are commonly known as peat, lignite, bituminous and anthracite coal. Peat, which may represent the first stage in coal formation, is formed chiefly by the growth of bog moss, sphagnum, in moist places. Lignite, or brown coal, represents the second stage in coal formation, and is brownish black or black in color, and often shows the vegetable structure. It burns readily with a long, smoky flame and has a lower heating power than true coal. It is usually found in the more recent geological periods. Bituminous coal represents the third stage in coal formation. It is denser than lignite and deep black in color. Thin sections under the microscope usually show traces of woody fiber, lycopod spores, etc. It burns readily with a yellow, smoky flame and has a much greater heating power than lignite. Most bituminous coal is of earlier age than lignite; but where the two occur in the same formation, as in parts of the west, the lignite is commonly in horizontal strata, while the bituminous coal occurs in areas of at least slight disturbance. Many bituminous coals cake to a hard mass, called coke, on losing their volatile hydrocarbons and other gaseous constituents by being heated to redness in an oven. Since some bituminous coals do not possess this characteristic it is customary to divide these coals into coking and non-coking coals. Anthracite coal represents the last stage in coal formation and shows no traces of vegetable structure, although plant impressions are often abundant in the rocks immediately above

and below it. It has a lower percentage of volatile hydrocarbons and a higher percentage of fixed carbons than any of the other varieties. On this account it ignites much less easily, and burns with a short flame, but gives great heat. The geological distribution of anthracite is more restricted than that of bituminous coal and, in fact, its occurrence is often more or less intimately connected with dynamic disturbances.

Conditions of Accumulation.—Plant remains accumulate owing to the fact that under certain conditions decay is retarded by the exclusion of air. These conditions are usually closely associated with water, either fresh or salt. The following conditions are the most important: (1) Accumulation due to algæ on the sea bottom beneath a sargasso sea, (2) marine swamps, including salt marshes and mangrove swamps, (3) delta deposits, (4) peat bogs, (5) coastal plain marshes.

Chemical Changes Occurring During Coal Formation.—Burial under water greatly retards oxidation and prevents rapid decay, but as oxidation slowly proceeds, the oxygen and hydrogen of the plant tissue, together with some of the carbon pass off in the form of carbon dioxide, carbon monoxide, marsh gas and water. As the process continues, an increasing percentage of carbon is left behind.

Effect of Heat and Pressure.—The first stage in coal formation is brought about by the exclusion of air, but pressure is necessary for further development. Peat is not changed to lignite until buried under many feet of sediments. Great pressure, possibly aided by heat, seems necessary for the change from lignite to bituminous coal. That anthracite coal is due largely to heat and pressure is generally believed. Heinrich Ries says: "Most of the anthracite coal in the United States occurs in the highly folded Appalachians of Pennsylvania. Such folding must have been productive of much heat and pressure, and that the folding has produced the anthracite is quite evident from the fact that these coal beds pass into bituminous coal when traced southward or westward into areas of less disturbance." There are cases where anthracite seems to have been produced by heat. *E. g.*, in the Cerillos coal fields of New Mexico a bituminous coal has been deprived of its volatile matter and converted into anthra-

cite at the contact of the beds with an intrusion of andesite. A similar change has taken place in the Crested Butte District of Colorado.

Structural Features of Coal Beds.—Coal usually occurs in beds interstratified with beds of sandstone, limestone, shale, etc., and is often underlain by beds of clay. An outcrop of a coal bed at first appears dark colored, but after a time the material is disintegrated and mellowed, the wash from it mingles with the soil and is termed the "smut" or "blossom" by the miners. In areas where the beds have been tilted and the slopes are steep the outcrops of the beds can usually be easily traced, but where the dip is low and the surface level, boring or pitting is often necessary. Coal beds or seams are seldom of uniform thickness over large areas. A bed which is of sufficient thickness to work in one mine may be so thin in a neighboring mine as to be scarcely noticeable. This irregularity may either be due to variation in thickness of vegetable accumulation or to local squeezing of the coal bed subsequent to its formation. These thinnings or thickenings are commonly called "pinchings" and "swellings."

In regions of pronounced folding the coal beds are usually found in separate synclinal basins, the intervening anticlinal folds having been worn away. Splitting is common with many coal seams; *e. g.*, the mammoth bed of the Anthracite basins in Pennsylvania splits into three separate beds in the Wilkesbarre basin. This splitting is due to beds of shale (called slate by the miners). Such a bed when narrow is called a parting. Other clay partings often occur cutting across the beds. These are due to erosion channels formed in the coal subsequent to its formation, and later filled by deposition of sand or clay. They may also be due to the filling of fissures produced during the process of folding. The following description gives the general character of one of our numerous coal fields. It is known as the Pennsylvania Coal Field, a region which has suffered much more disturbance than most of our coal fields. It lies in the east-central part of Pennsylvania and covers an area of about 3,300 square miles. About one seventh is underlain by workable coal measures. Intense folding has produced a series of synclines and anticlines. The coal exists in the synclines but has been swept off from the anticlines. Indeed it is estimated that

from 94 to 98 per cent. of the coal originally deposited has been removed from this field by denudation. The coal measures consist of beds of sandstone, shale and clay with coal beds at intervals varying from a few feet to several hundred feet, though rarely exceeding two hundred feet. The coal beds occur throughout the entire section of the coal measures, but are most important in the lower 300 to 500 feet. Below the productive measures is the hard Pottsville conglomerate which forms an important stratigraphic horizon recognizable by its lithological character and bold outcrops.

Character and Distribution of the Coals of the United States.—Before taking up the distribution of coal throughout the United States it is interesting to compare the production with that of foreign countries. Fig. 15, page 192, brings out the comparison very clearly. The 1907 production is given for all countries except Russia and Finland, India, and a few of the lesser important ones which are grouped together. The production for Russia and Finland is for 1906 as is also that of India. The United States produced 39.7 per cent. of the total world's supply of coal. This country only supplanted Great Britain as the leading coal producer of the world nine years ago, yet in 1907 it produced 180,392,747 short tons, or 60 per cent. more coal than Great Britain, and 253,589,819 short tons or over 100 per cent. more than Germany. Except for Great Britain, the United States in 1907 produced more coal than all the other countries of the world combined. It is interesting to note that more than 98 per cent. of the total world's production of coal is from countries lying north of the equator.

We shall now consider the distribution of coals throughout our own country. Fig. 16, page 193, shows clearly the relative importance of the different states from the standpoint of production. This figure is interesting not only because it shows the tonnage of the various states, but because it gives the value of the product from each state. Such factors as character of the coal, supply and demand, etc., have created considerable variation in the price per ton throughout the different states. For instance, satistics show that the average price per ton for the three states, Idaho, Nevada and Nebraska,

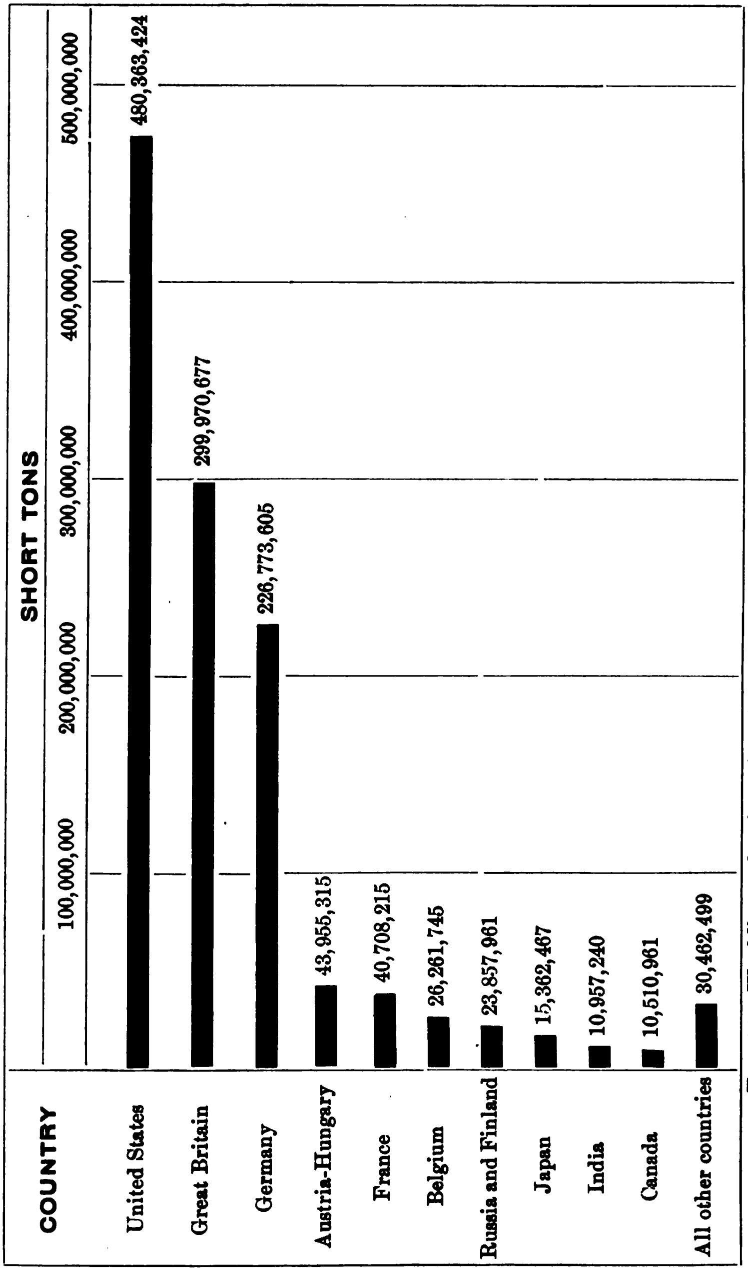

FIG. 15. World's production of coal. (From U. S. Geological Survey, Bulletin, p. 64.)

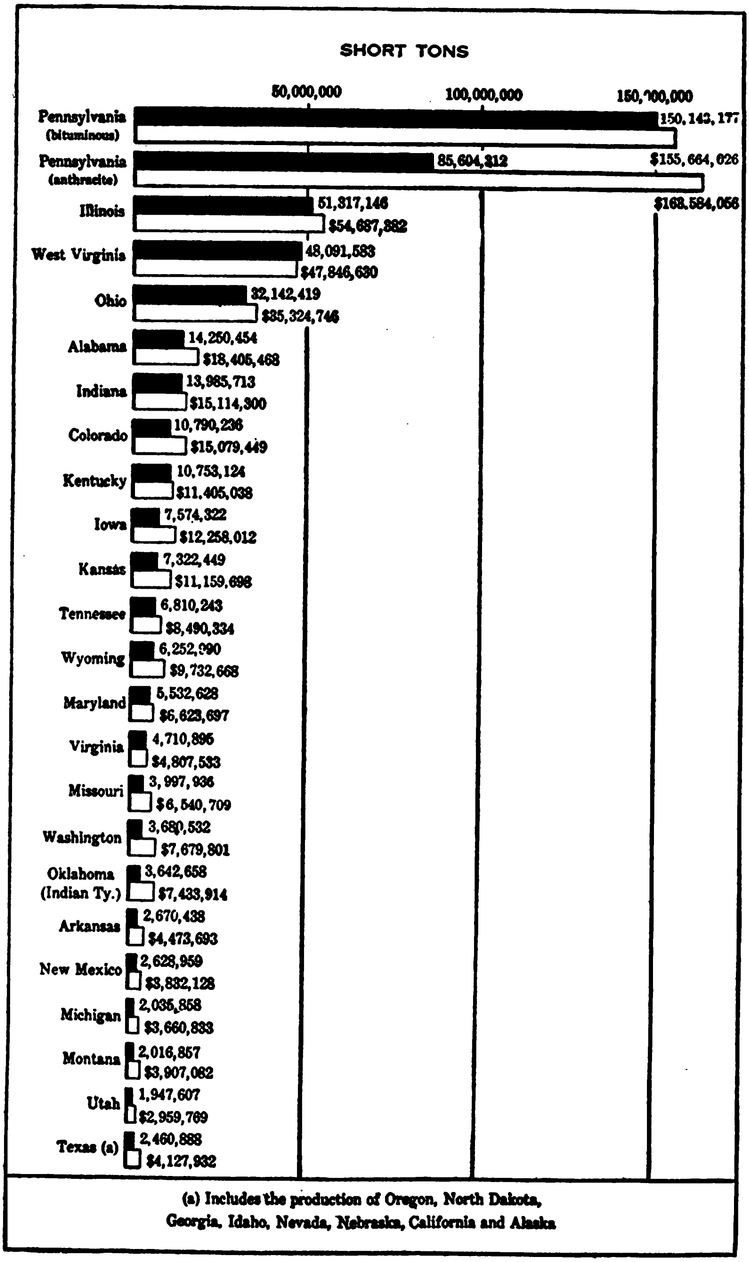

FIG. 16. Production of coal in the United States in 1907, by states. (From U. S. Geological Survey, Bulletin, p. 46.)

for 1907, was 4.10, while the average price per ton for West Virginia for the same year was 99 cents.

The U. S. Geological Survey recognizes the following six classes: (1) Anthracite, (2) semianthracite, (3) semibituminous, (4) bituminous, (5) subbituminous and (6) lignite, based chiefly upon the relative abundance of the volatile hydrocarbons and the non-volatile or fixed carbon. This relation is expressed by the fuel ratio, a quantity obtained by dividing the percentage of fixed carbon by the percentage of the volatile combustible constituents of the coal. In general, the fuel value or heating power increases with the increase of the fuel ratio, but this increase in fuel value, however, increases only to a certain point, beyond which the difficulty of effecting combustion more than makes up for the greater amount of heat evolved. For instance, the graphitic anthracite of the Rhode Island field cannot properly be regarded as a fuel, for there the percentage of volatile constituents is so small that these have to be supplied by the addition of another coal before it will burn.

Probably no more complete and up-to-date map showing the areal distribution of coal throughout the United States can be found than that prepared by Marius R. Campbell. This map accompanies the chapter on "Production of Coal," by Edward W. Parker ("Mineral Resources," 1907).

The map is particularly valuable because upon it Mr. Campbell shows the following: (1) Areas containing workable coal beds, (2) areas that may contain workable coal beds, and (3) areas probably containing workable coal beds under such heavy cover as not to be available at present. Areas underlain by anthracite, semi-anthracite, semi-bituminous and bituminous coals are given a neutral gray color. Areas underlain by subbituminous coal are given an olive green color, and areas underlain by lignite are represented in yellow. Mr. Campbell divides the coal-producing areas primarily into six provinces as follows: (1) The Eastern province including (*a*) all of the bituminous areas of the Appalachian region; (*b*) the Atlantic coast region, embracing the Triassic fields near Richmond and the (Deep and Dan) River fields of North Carolina; and (*c*) the anthracite region

of Pennsylvania. (2) The Gulf province which includes the lignite fields of Alabama, Mississippi, Louisiana, Arkansas and Texas. (3) The Interior province, which includes all of the bituminous areas of the Mississippi Valley region and the coal fields of Michigan. This province is subdivided into the eastern region, including the coal fields of Illinois, Indiana and western Kentucky; the western region, which includes the fields of Iowa, Missouri, Nebraska, Kansas, Arkansas and Oklahoma; and the southwestern region, including the coal fields of Texas. (4) The northern or great plains province, which includes the lignite areas of North and South Dakota, and the bituminous and subbituminous areas of northeastern Wyoming and northern and eastern Montana. (5) The Rocky Mountain province, which includes the coal fields of the portions of Montana and Wyoming, which are in the mountainous districts of those states, and all the coal fields of Utah, Colorado and New Mexico. (6) The Pacific Coast province, which includes all of the coal fields of California, Oregon and Washington.

Geologic Distribution of Coals in the United States.—The coal-bearing beds of the United States range in age from Carboniferous to Tertiary. In a general way the Carboniferous coals occur east of the 100th meridian, Cretaceous coals between the 100th and the 115th meridian and the Tertiary coals chiefly between the 120th meridian and the Pacific coast. Exceptions are the occurrence of a small area of Triassic coals in Virginia and North Carolina, a large Tertiary area of lignites in the gulf states, the Fort Union, Tertiary lignite area in North and South Dakota and eastern Montana and also the Tertiary subbituminous coals of the Bull Mountain, Musselshell and Red Lodge fields of southeastern Montana and the Tertiary subbituminous coals of the Green River basin and Hanna field in southeastern Wyoming. In the main the best coals of the country are of Carboniferous age and are found in the Appalachian, anthracite, northern, eastern, western and southwestern regions of the eastern and interior provinces. In this broad area the coals of highest grade occur in the anthracite region, along the eastern front of the Appalachian region, and in the Arkansas fields of the western region, near centers of great disturbance and mountain making.

Much attention has been given of late years to the necessity of conserving the mineral fuels of this country for the use of future generations. A great deal of work has been done during the last few years by the U. S. Geological Survey on the subject of coals. From the data at hand and from the limit of workable depth as based upon actual mining conditions abroad, especially in Belgium, Marius R. Campbell reasons as follows: Taking the limit of workable depth for coal as 3,000 feet and for lignite as 1,000 feet, and the minimum minable thickness of coal as 20 inches, and of lignite as 3 feet, with a total accessible area of 327,000 square miles, he reasons that our existing coal beds carry an estimated content available for future use of nearly 2,000 billion tons. The rate of consumption cannot be predicted with certainty, but if the rate of increase that has held for the last fifty years is maintained, the supply of easily available coal will be exhausted before the middle of the next century.

Pacific Coast Region.—1. Bering River Area.—The area of coal outcrop is at least 30 square miles. It is situated entirely within the valley of Bering River and on the northern tributaries of that stream. The southern boundary of the area coincides with the position of Bering River. and Bering Lake. Coal extends as far north as Martin River Glacier.

The coal-bearing rocks have been called the Kushtaka formation and consist of probably several thousand feet of sandstone, shales, arkose and volcanic ash. The sediments contain fossils of Oligocene age and are probably equivalent to the Kenaï formation of the Cook Inlet region. The prevailing strike of the rocks is N. 40° E. with a northwest dip of about 45°.

Coal Seams.—Several valuable seams have been opened in the valley of Canyon Creek and on the opposite side of Carbon Mountain. Ffteen openings in the same seam on Carbon Mountain showed thicknesses of from 9 to 25 feet. A dozen workable seams have been reported from that locality. In Bulletin 259 U. S. G. S. George C. Martin mentions the following seams of coal. Four seams of coal on the east bank of Canyon Creek, one having a thickness of 2 feet 9 inches. Another seam

four miles above the mouth of the creek has a thickness of 4 feet two inches. A section on the south end of Carbon Mountain shows beds of coke from one to five feet in thickness alternating with beds of sandstone. Also many seams, some of which reach a thickness of more than 20 feet have been found along the valleys of Shepherd Creek, Carbon Creek, Stillwater Creek and near Kushtaka Lake.

The character of the coal is similar in all the seams. It resembles the harder bituminious coals of the East more than it does anthracite. Fourteen analyses of coals from different parts of the region show the percentages of volatile matter to vary from 7 per cent. to 22 per cent. That of fixed carbon from 77 per cent. to 93 per cent. The fuel ratio for the fourteen samples varies from 4 to 13½. 13½ is, however, exceptionally high; the average fuel ratio is about 5.

The Matanuska and Talkeetna Basins.—This region lies immediately northeast of the head of Cook Inlet. The rocks range in character from crystalline schists to unconsolidated Quaternary stream and glacial gravels. The mass of Talkeetna Mountains is made up of granite of Middle Mesozoic age. This granite core is bounded on the south by a narrow belt of albite and garnetiferous mica schists and this is bounded on the south by another belt of granite. The core of granite is bordered on the northwest by a series of slates and graywacke slates. Jurassic strata are developed extensively east of Chickaloon Creek. They comprise two unconformable series. The lower consists of andesite breccias, agglomerates and amygdaloids. This is overlain by several thousand feet of sandstone, shales and conglomerates with some interstratified tuff and arkose. Upper Eocene rocks are represented by the Kenai formation, a series of folded sandstones, shales, arkoses and conglomerates carrying beds of bituminous coal. A series of post-Eocene basaltic lavas and associated pyroclastics overlie the older rocks unconformably. They reach a thickness of 1,000 feet and form the summit topography of much of the area. The most recent deposit of the region is glacial gravel.

Coal.—Coal occurs on Tsadaka, Eska, Kings and its tributaries, Chickaloon, Coal, Hicks and Billy Creeks and

the north fork of Melchina River; along the southern flank of Anthracite Ridge; and in the banks of Matanuska River, about three miles above the mouth of Chickaloon Creek. It has also been reported from Little Susitna River, Willow Creek, the Kashwitna and the Chunilna, and from a creek on the south side of the Matanuska nine miles above Coal Creek. The area of coal-bearing rocks can be subdivided into three fields: (1) The Matanuska field, comprising the valley floor of Matanuska River west of the mouth of Hicks Creek. This field is underlain by Tertiary strata containing bituminous coal of various grades. (2) The Anthracite Ridge field, comprising a small area along the southern flank of the Talkeetna Mountains between Boulder and Hicks Creek. The coal here is anthracite but the age is uncertain. (3) Northeastern field, an area drained by the headwaters of Matanuska River and the adjacent areas in the Copper and Susitna drainages. The coal is of Jurassic age, usually lignitic, but locally semi-anthracitic.

Nineteen samples of coal taken from different localities along Chickaloon, Matanuska, Kings, Coal, Young and Eska Creeks give percentages of volatile matter and fixed carbon such that the fuel ratio varies, for the most part, from about two to three and one half.

Southwestern Alaska.—In Bulletin 259, U. S. G. S., Ralph W. Stone describes the coal fields of southwestern Alaska in geographic order from the head of Cook Inlet to the Aleutian Islands. The following are some of the principal points brought out by him in his brief descriptions.

Tyonok.—Brown lignite occurs in the bluffs at this point near the head of Cook Inlet. The section in the bluff is composed of sandstone, shale and coal seams dipping southeast from 35° to 60° and striking north-northeast. This strike would carry the beds to a point about ten miles up the Chulitna, where coal is reported. Thirty-six seams, large and small, are reported along the beach, some of which may be repeated by faulting. The thickness varies from 1 to 15 feet. The coal is of poor grade and the seams are much broken by clay and sandstone partings. This low-grade lignite is often little more than a mass of carbonized wood. Four analyses showed not less than 31 per cent. fixed carbon. It is the

chief fuel of the steamer "Tyonic," which plies in Cook Inlet.

Kachemak Bay.—This is an arm of Cook Inlet 25 miles long and from 3 to 10 miles wide, which indents the western side of Kenai Peninsula. A low, narrow point extends out into the bay near its entrance. The seaward end of this spit is the site of Homer, a post-office and steamer landing. The north shore is comparatively smooth, while the eastern and southern shore is made irregular by coves, headlands, and islands. North of the bay lies a great plateau having a general elevation of 1,000 feet and a shore which varies in height from 50 to 400 feet. The shore bluff is cut by canyons at a number of places between Homer Spit and the head of the bay. On the south side of the bay is a mass of rugged mountains with six glaciers. Both geology and topography differ on the two sides of Kachemak Bay. The mountains on the south consist of crystalline and schistose rocks. The plateau on the north consists of an extensive Tertiary lignite formation known as the Kenai formation. Coal seams are almost continuously exposed from Anchor Point to the head of the bay, a distance of 40 miles. The beds are interbedded with soft sandstone, shale, clay and fine conglomerate. These rocks strike nearly east and dip northward at angles as high, in places, as 20°. Between 2,000 and 3,000 feet of strata are exposed in the sea bluff from Anchor Point to the head of the bay. Anchor Point is near the base of the series and coal has been found 15 miles inland from the head of the bay. In the cliff at Bluff Point 471 feet of strata contain 18 feet of coal in seams ranging in thickness from 3 inches to 4½ feet. The point chosen by the Cook Inlet Coal Fields Company to develop a mine is at Mine Camp. The section at this point contains nine coal seams which have a total thickness of 24 feet. The smallest seam in the section is 5 inches and the largest 7 feet 5 inches.

The first prominent coal locality east of Homer Spit is the Bradley seam near Fritz Creek. This seam aggregates 7 feet with only 18 inches of clear coal. From Fritz Creek to McNeil Canyon the coal seams are thin and of little value. A section in McNeil Canyon measures 325 feet and contains 21 feet 4 inches of coal. Small

seams also occur in the canyons of Cottonwood and Falls Creeks. The Kachemak Bay coals carry a large quantity of moisture; about 15 to 20 per cent. would be held by the marketed coal. The fuel ratio is low and its bulkiness is an objection. It can be mined in large quantity with little difficulty and is an excellent house coal. If put on the market it must compete with higher grade lignites from Puget Sound and with bituminous coal from Vancouver Island. It could only do this if mined on a large scale and put on the market at a low price commensurate with its quality.

Port Graham.—The small bay of Port Graham on the east side of Cook Inlet lies half way between Kachemak Bay and the southern end of Kenai Peninsula. On the north side of Port Graham is a cove which was called Coal Bay by Portlock, who discovered coal here in 1786. A series of sedimentary rocks composed of sandstone, shale, clay and coal lies between igneous formations 1,000 feet apart. Two outcrops of coal occur at this place. A tunnel was driven on one of the coal seams. At the mouth of this tunnel, now inaccessible, there are between 8 and 9 feet of coal. A shaft was also sunk from the top of the hill. This shaft was reported to be 180 feet deep, passing through five seams of coal varying from 5 to 9 feet in thickness. 2,700 tons are reported to have been mined. The coal is black brilliant lignite. One analysis gives the fuel rates as 1.04

Cape Douglas.—Coal has been reported at this locality but what was reported as coal is merely black shale.

Other Localities.—Coal has been reported from the following localities but the value of the deposits do not require any especial description: Amalik Harbor, Katmai Bay, Cold Bay Ugashik Lake, Kodiak Island, Sitkinak Island and Aniakchak Bay.

Chignik Bay Region.—The deposits in the vicinity of Chignik Bay seem to merit a little further discussion. Coal has been mined constantly at one locality in the vicinity of this bay for nearly twelve years. It is now known to occur at four localities in this region, viz., Chignik River, Whalers Creek, Thompson Creek and Hook Bay.

The mine on Chignik River has supplied the Alaska

Packers Association with about 600 tons of coal annually for a number of years. The coal beds dip northeast at an angle of 20° and strike N. 5° W. Two six-foot tunnels have been driven on the seam. The upper tunnel runs in 250 feet, the lower one 500 feet. Coal is carried from the breast of the rooms to the tunnel in chutes, taken out in tram cars and dumped directly upon the barge. One seam shown in the tunnel is overlain by shale and this by sandstone. The coal varies from 5 feet to a few inches in thickness and is solid and bright, and is a fairly satisfactory steaming coal with a fuel ratio of 1.12.

The coal as exposed at Whalers Creek is lignite, much the same as that mined at Chignik River. The continuity of the beds is interrupted by a series of faults which have broken the formation up into a series of blocks.

In the valley of Thompson Creek are several seams of coal. The coal, which is a fair grade of lignite, varies in thickness from 3 to 5 feet. At Hook Bay two beds of coal are reported, 5 and 6 feet thick respectively, separated by 2 feet of bony shale.

Herendeen Bay.—This bay is a branch of Port Moller, and is situated on the north side of Alaska Peninsula. It is reached from Portage Bay on the southern side of the peninsula by a trail about nine miles long. Twenty square miles is supposed to be underlain by coal between Port Moller and Harendeen Bay. Attempts at development have met with little success because of the prevalence of faults. The coal is bituminous in character and the only analysis available gives the fuel ratio as 1.21.

Unga Island.—According to G. C. Martin the lignite of Unga Island is restricted in area to the peninsula on the west side of Zachary Bay. It occurs in the soft shale and sandstone of the Kenai formation of Oligocene age. These Tertiary rocks dip northwest at various angles, reaching in places 20°. They are adjoined on the south by crystalline rocks, principally andesites.

There are some other minor localities where coal beds are reported, but it is believed that the principal localities have been mentioned.

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The Interior Region.—Yukon Basin.—In Bull. 218, U. S. G. S., Arthur J. Collier describes briefly the coal beds along the Yukon River. The main points concerning the coal beds, brought out in this report, are as follows: The Yukon has a length from its mouth to its source of 2,400 miles, of which 1,300 miles are in Alaska. Coal of commercial importance is found in two different geologic horizons along the Yukon, namely, in the Upper Cretaceous and in the Kenai series of the Tertiary. The coals of different ages, however, have not been differentiated. The map accompanying the above report shows the area underlain by coal-bearing rocks and also that underlain by non-coal-bearing formations, comprising metamorphosed sediments, Yukon silts, recent alluvium and igneous rocks. The Kenai series occurs in small, isolated areas along the Yukon above the mouth of the Tanana. These represent remnants of larger areas, which are now infolded with older beds and also separate basins of deposition. The coal-bearing beds of the series rest unconformably upon nearly all the older formations which have been identified in Alaska, and their conglomerates contain pebbles derived from them. The coal beds are not confined to any definite horizon of the formation. In some instances they lie near the bottom of the formation, while in others they lie near the top. All the coals examined along the Yukon in the Kenai series above Tanana are either lignites or are lignitic in character.

The Upper Cretaceous, which is the lower coal-bearing horizon, is extensively developed on the lower Yukon. Outcrops are seen along the north bank for about two hundred miles below the mouth of Melozi River, only interrupted here and there by either silt deposits or narrow belts of intrusive rocks. This area is thought to extend westward to Norton Sound, where coal-bearing beds have been found. Coals occur in the lowest as well as in the highest beds, and have higher fuel ratios than the Tertiary coals and are of somewhat better quality. For convenience of description the Yukon region is divided into three provinces. The Circle Province includes all known coal-bearing areas along the Yukon between Circle and Fortymile. The Rampart province embraces the scattered coal-bearing areas between the Yukon flats and the Melozi River. Nulato province includes the coal deposits along the Yukon from Melozi River to the delta.

The coals of the three provinces combined present great variation in quality, due partly to primary differences in composition and in part to metamorphic influences which have acted more or less locally. They range from high-grade lignites to semi-bituminous coals. In the classification of the Yukon coal Mr. Collier makes the term lignitic coal include those grades which, by proximate analysis, fall between typical lignite and typical bituminous coal. In his table of proximate analyses the lignitic coals are those in which the quotient of the fuel ratio divided by the percentage of water falls between 9 and 11 in value. The table gives proximate analyses of seventeen samples of coal from the Circle province, the average fuel ratio of which is 1. It also gives proximate analyses of seven samples from the Rampart province, the average fuel ratio of which is .87. Twelve samples from the Nulato province give an average fuel ratio of 1.85. The coals from this province are relatively high in fuel ratio and are all classed as bituminous. Those from the Rampart province are comparatively low in fuel ratio and are either lignite or lignitic. Those from the Circle province are relatively intermediate in fuel ratio but are almost entirely either classed as lignite or lignitic.

Copper River Region.—In professional paper No. 41, by W. C. Mendenhall, coal is mentioned in the following localities in the Copper River region:

Chistochina River.—Within one and one half miles of the head of the Chisna, along the north wall of the valley are soft greenish and buff shales with loose sandstones and fine conglomerates. Associated with these rocks is a medium grade lignite.

Gakona River.—Between the head of Gakona and the west fork of the Chistochina are clay and sand beds with occasional thin conglomerates of Miocene or Eocene age. Lignite occurs sparingly in this formation, generally in the form of single trunks with the woody fiber and structure well preserved. No deposits, however, of much commercial importance were seen.

Coal has also been found along Bubb Creek, one of the principal tributaries of the Tazlina, and along the upper Chitistone, and sediments which resemble the coal-bearing rocks of upper Eocene age occur along the middle part of the Cheshnina.

The Bonnifield and Kantishna Regions.—In Bull. 314, U. S. G. S., L. M. Prindle describes deposits containing lignite in the northern foothills of the Alaska range between Cantwell River and Wood River. These deposits occupy valleys between east-west ridges of old metamorphic rocks. They are only slightly consolidated, are deeply cut by the drainage system, and are the remnants of much larger masses as indicated by small isolated patches on the upper slopes of the ridges. They have been folded, the flexures being chiefly broadly open with dips of 30° to 35°. The deposits consist of sands, clays, coal and gravel. The sands and clays have become indurated in many places by the burning of the coal beds and baked to a red color. The greatest observed thickness of these deposits was approximately 3,500 feet, about half of which consists of gravel. The age of the coal-bearing member has been determined to be Tertiary. There is a close resemblance between these coal-bearing deposits with their overlying gravels and the Kenai beds of the Seventy mile Creek area near Eagle. The most prominent exposures of coal are on Healy Creek and Lignite or Hosanna Creek. A section about two miles above the

mouth of Healy Creek shows seven beds of coal 20 feet or more in thickness, aggregating 175 feet and sixteen thin beds higher in the deposit aggregating 35 feet. An analysis of Healy Creek coal gave percentages as follows: Moisture, 13.02; volatile matter, 48.81; fixed carbon, 32.4; ash, 5.77; sulphur, .16.

A section on Lignite Creek six miles above the mouth showed a total thickness of 129 feet of coal in beds from 1 to 32 feet thick.

Another section near the head of Lignite Creek gave a total coal thickness of 45 feet in beds varying in thickness from 1 to 10 feet.

These two valleys contain a large quantity of coal, but Cantwell River is unnavigable and the locality is about thirty miles south of the Tanana. The best outlook for these coals seems to be their transformation into electrical energy which could be transported to the Fairbanks district about 75 miles distant. Coal-bearing beds are also exposed on Coal Creek, Mystic Creek and east of Wood River. There are approximately 600 square miles of the younger deposits between Cantwell and Wood Rivers. To what extent they are underlain by coal has not been determined. It is quite probable that there is considerable coal between Cantwell and Toklat Rivers.

References for the Interior Region.

Collier, A. J. Coal Resources of the Yukon Basin, Alaska. Bull. U. S. G. S., No. 218, 1903, 71 pp.

Mendenhall, W. C. Geology of the Central Copper River Region, Alaska. Professional Paper U. S. G. S., No. 41, 1905, pp. 123–125.

Prindle, L. M. The Bonnifield and Kantishna Regions. Bull. U. S. G. S., No. 314, pp. 221–226.

Bering Sea and Arctic Slope.—Cape Lisburne Region.—Cape Lisburne marks the northwestern extremity of a land mass projecting into the Arctic Ocean from the west coast of Alaska. It lies one hundred and sixty miles north of the Arctic Circle, three hundred miles directly north of Nome, and is the only point in Alaska north of Bering Strait where hills above 1,000 feet in height approach the sea. The geological features of the surrounding region are described by Arthur J. Collier in

Bull. 278, U. S. G. S. The only economic resources known to be of commercial importance are the coal deposits. There are no harbors for sea-going vessels, but in calm weather or when the winds are from the south coal can be boated or lightered to ships anchored from one to two miles off shore. There are two distinct coal-bearing formations in the region, one lying east of Cape Lisburne and containing low-grade bituminous coal of Jurassic age. The other lies south of the cape and contains high-grade bituminous coal of lower Carboniferous age.

The Mesozoic Coal Field.—The coals of this field occur in the Corwin formation of Jurassic age. The same coals have been found in the interior twenty miles south of Cape Beaufort and similar coals have been reported three hundred miles east of Cape Lisburne. It is, therefore, safe to say that the coal-bearing area is not less than three hundred square miles, though it may be much greater.

The topography of the field consists of low, rounded hills and ridges usually less than 600 feet in elevation, which trend parallel with the strike of the bed rock and are usually formed by outcrops of the harder strata. The only mines which have been worked lie between Corwin Bluff and Cape Sabine. The beds which seem to be of economic importance fall readily into two groups, the Corwin and Thetis. The coal beds if the Corwin group outcrop in the sea cliffs east and west of Corwin Bluff which is a cliff 200 feet high about 28 miles east of Cape Lisburne. Those of the Thetis group outcrop on the coast six miles east of Corwin Bluff and are stratigraphically about 8,000 feet below the lowest beds of the Corwin group.

Paleozoic Coal Fields.—The coal-bearing beds are of Carboniferous age and apparently near the bottom of the series. Owing to the complicated structure of the Lower Carboniferous series the coal-bearing formation outcrops in limited areas. The beds are very much crumpled and broken. The largest bed seen is not over four feet thick, but the coal is of high grade suitable for special purposes, such as blacksmithing and metallurgy, and will probably compare favorably as a heat producer,

with any coal used on the Pacific coast. On account of their complicated geologic structure they are more difficult to mine than the Mesozoic coals, but, on the other hand, anchorages south of Cape Lisbourne are protected from northeast and south winds, and deep water can be found nearer shore than at Corwin Bluff. A table of proximate analyses published by Mr. Arthur J. Collier in Bull. 278, U. S. G. S., shows the relation between the Mesozoic and Paleozoic coals. Analyses of twelve samples of Mesozic coals give the following averages:

	Per Cent.
Fixed carbon	46.83
Hydrocarbons	38.42
Moisture	9.46
Ash	5.24
Sulphur	.38
Fuel ratio	1.21

Analyses of three samples of Paleozoic coals gives the following averages:

	Per Cent.
Fixed carbon	75.94
Hydrocarbons	17.47
Moisture	3.66
Ash	2.92
Fuel ratio	4.46

Seward Peninsula.—Mr. Fred H. Moffit in Bull. 247, U. S. G. S., describes the coals of Seward Peninsula, and from his very brief description the following may be noted. Coal of lignitic character has been seen near the point where the Kugruk River makes its big bend to the west, and also in the gravels of Kugruk River above Chicago Creek and on French Creek. There may be a limited demand for this coal in spite of its inferior quality as long as gravels are being worked on nearby creeks. For coking purposes it is superior to wood, but as a steam coal it has not been very successful.

References for Bering Sea and Arctic Slope.

Brooks, A. H. Coal Resources of Alaska. 22d Ann. Report, U. S. G. S., pt. 3, 1902, pp. 515–571.

Collier, A. J. Geology and Coal Resources of the Cape Lisburne Region. Bull. U. S. G. S., No. 278, 1906, 54 pp.

Moffit, F. H. The Fairhaven Gold Placers, Seward Peninsula, Alaska. Bull. U. S. G. S., No. 247, 1905, p. 67.

Schrader, F. C. Reconnaissance in Northern Alaska Across the Rocky Mts., Along Koyukuk, John, Anaktuvuk, and Colville Rivers, and the Arctic Coast to Cape Lisburne, in 1901. Professional Paper U. S. G. S., No. 20, 1904, pp. 106–114.

It has been shown that coal-bearing rocks have a wide distribution in Alaska; that the coals are chiefly lignites, with some bituminous coals, and in a few localities semi-anthracites. Developments have been entirely along waterways where the coal could be handled cheaply and receive the benefit of water transportation. At a few localities in southern Alaska where attempts have been made at development the faulted condition of the seams have often prevented economic mining. The development of the Yukon coals is dependent entirely upon their finding a local market.

PETROLEUM AND NATURAL GAS.

Crude petroleum is a liquid of complex composition and variable color and density. It consists of a mixture of hydrocarbons. Natural gas consists chiefly of marsh gas. It is colorless, odorless, and when mixed with air is highly explosive.

Mode of Occurrence.—Oil is rarely found without gas, and saline water is likewise often present. If the containing strata are horizontal, the oil and gas are usually irregularly scattered, but if tilted or folded they collect at the highest point possible. Observation has led to the "anticlinal theory" which implies that in folded areas the gas collects at the summit of the fold, with the oil immediately below, on either side, followed by water. This theory, of course, implies that the oil-bearing strata shall be capped by a practically impervious one. This theory is well established for many localities. A rival theory is that the oil has accumulated in porous areas of rocks, perhaps ancient shore-line deposits. It also applies in many localities. The quantity of oil which a cubic foot of apparently dense rock can hold is often surprising. It is estimated that fairly productive sands may hold from six to twelve pints of oil per cubic foot, but that

probably not more than three fourths of the amount stored in the rock is obtainable.

Pressure of Oil and Gas Wells.—The force with which oil and gas sometimes issue from a well indicates the pressure under which they are confined. This force is sometimes sufficient to blow out the drilling tools and casing, as well as to cause the oil to spout many feet into the air. The famous Lucas well at Beaumont, Texas, in 1901, gushed for nine days a six-inch stream to the height of 160 feet at the rate of 75,000 barrels per day. This however, is small compared with the records of some Russian oil wells. The maximum pressure which a well develops when closed is called "rock pressure." There are two main theories for the origin of oil.

Inorganic Theory.—The most important theory for the inorganic origin of oil was that of Mendeljeff, a Russian chemist. According to this theory, the interior of the earth contains metallic iron, as well as carbide of iron like that found in meteorites. Water percolating down through the earth's crust, on reacing the heated interior, becomes converted into steam, which, attacking the carbide of iron, forms hydrocarbons. These are forced to the surface by the expansive force of steam. This theory is reasonable from a chemical standpoint, but does not accord with facts of occurrence. Such an origin would cause wide distribution through the oldest rocks of the earth's crust. On the contrary it is known only in those rocks at one locality, in Ontario, where a hard, compressed asphalt is found in crystalline rocks.

Organic Theory.—This theory considers that petroleum has been derived from either animal or vegetable matter by a process of slow distillation. The several arguments in favor of this theory are, as stated by Hienrich Ries: "(1) Petroleum is a combustible substance and all other similar combustibles have originated organically. (2) It is possible to produce artificially from either animal or vegetable substances, both gaseous and liquid compounds which are closely analagous to those found in petroleum and natural gas. (3) These substances occur in fossil-bearing rocks. (4) They are practically absent from the crystalline rocks. (5) In some places these substances occur in close proximity to fossils. (6) Natural gas is actually generated in coal seams."

Distribution.—Petroleum is widely distributed geologically, being found in rocks from Ordovician to most recent, the occurrence in the Paleozoic strata being chiefly in the eastern United States, those of the post-Carboniferous strata in the western and southern states. Natural gas in the United States is chiefly obtained from the Paleozoic formations.

Hancock, Eugene T.
AUTHOR

Notes on applied geology.
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